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UNITED STATES DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

WASHINGTON 25, D. C.

RATES OF SEDIMENT PRODUCTION IN SOUTHWESTERN UNITED STATES

By

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January 1945

SCS-TP-58

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INTRODUCTION

Sediment is one of the major problems involved in utilization of the water resources of the Southwestern States. The enormous quantities of solid matter carried by many Western streams has a significant and often deciding influence on the location, design and maintenance of storage reservoirs for power, irrigation, flood control and water supply, and of irrigation and drainage developments. Familiar examples are the large storage of 5,000,000 acre-feet or more provided for silting behind Boulder Dam and the elaborate desilting works constructed at the head of the new All-American Canal.

Despite the critical importance of sediment in Western water developments, accurate records of the sediment loads of streams are extremely meager. Such records as exist are widely scattered, often in obscure publications or in private files. Where published, the summary data are often difficult to evaluate from lack of information on the manner of their collection.

In this publication an attempt is made to compile, evaluate and translate into comparable units all of the known data that might be usable in estimating quantities of sediment carried by streams in the region embracing the Great Basin interior drainage, the Colorado and Gila River watersheds, and the Rio Grande and Pecos River watersheds above the junction of these streams. The geographic locations of the records shown in Figure 1 are numbered to correspond with the numbers of the records given in Table 1.

From these basic data and consideration of various factors affecting the sediment load of streams, estimates are made of the probable long-term average annual sediment production. Considering the nature of the records, it is obvious that such estimates involve a large element of personal judgment, which must be based on assumptions not subject to rigorous testing and confirmable only in the distant future when, it may be hoped, many years of substantiating records will be available. To such criticism as the reader may have for the methods employed or the conclusions reached, the writer's only defense is the demonstrated practical need and frequent requests for such estimates and the obviously wide departure of many of the basic records, as published, from probable long-term averages. The status of sediment load records is today about the same as the status of stream flow records in 1900 or earlier. Recognition of the importance of collecting accurate sediment load data on Western streams is about 50 years behind times.

The long-term estimates given in Table 1 are supplemented by a discussion of the sediment production rates in each of the major subdivisions of the region treated in this publication.

UNITS AND CONVERSIONS USED IN TABLE 1

Column 3.—Drainage areas are taken from the best available sources, and no effort has been made to redetermine areas for the purpose of this paper. First preference has been given to the latest drainage area figures published in U. S. Geological Survey Water-Supply Papers (28). These figures frequently differ from those published originally, as in connection with the Stabler records (21) computed by Stevens (22). The letter "A" means that the figure is known to be approximate. The letter "N" means net area below an upstream reservoir. Where large areas within the topographic watershed boundary are known to be non-contributing for either water or sediment, they are excluded.

Column 4.—The years given are those in which the record begins and ends.

Column 5.—Where the record is only slightly longer or shorter than an even number of years, and particularly where the fractions of years come in the low-runoff season, the computations have been based on an even number of years. A "+" or "-" sign indicates that the actual record is more than 15 days longer or shorter than the figure given. If part of the record has been excluded or missing days or months estimated to make an even number of years, the "+" or "-" sign is shown in parenthesis.

It is often practically impossible to establish exactly the date of beginning of storage and sedimentation in reservoirs. Available records for the older reservoirs usually give only the year of completion. Actually the gates may have been closed and storage begun as much as one whole runoff season sooner or later. Where the beginning of storage is not known to the closest month, the letter "A" for approximate, follows the figure. The letter "R" indicates the number of runoff seasons on ephemeral streams. The letter "W" means water years, October 1 through September 30, and "C" means calendar years.

Column 6.—The average annual runoff during the period of sediment record has been compiled from all available sources, preference being given to the latest figures published in U. S. Geological Survey Water-Supply Papers (28). The runoff for the entire period has been used where it is 1± years and is so designated by the letter "P". If the record is longer, the runoff has been divided by the number of years shown. Short gaps in the runoff record have been estimated from records of other stations, rainfall, etc. The letter "A" means approximate, and "E" means estimated without current meter readings.

Figure 1.–Location of sediment records in Southwestern United States

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The average annual runoff for the period of stream flow measurement when given in the footnotes, Appendix A, has been computed, either by the equation:

(1) $$R = 722.7 (Q_{mean}) \qquad (1)$$

where R = Average annual runoff in acre-feet

Q_{mean} = Mean discharge in second-feet for entire period of record, as reported in U. S. Geological Survey Water-Supply Papers

722.7 = Coefficient 1.98 (to convert c.f.s. to A.F./day) x 365 (days per year)

(2) Or, addition of yearly values of runoff from Water-Supply Papers and other sources.

Column 7.--These figures are obtained by dividing Column 6 by Column 3, except where the letter "G" is given the gross drainage area is used instead of the area shown in Column 3.

Column 8.--This column gives only records obtained from reservoir sedimentation surveys. The data include not only the volume of sediment measured below spillway level, but also, where available, the above-crest and up-valley deposits caused by the reservoir (except Record 64). Where the data are based on reconnaissance surveys the letter "E", for estimated, follows the value. The values do not include the sediment that passes through the reservoir and over the spillway or through outlets in the dam (except Record 64). These losses have been taken into account in the estimates in Column 13, using curves previously published by the writer (5).

Column 9.--All values in this column for which there are no corresponding values in Column 8, were obtained from suspended-load measurements only and do not include bed load. Bed load is taken into account, however, in the estimates in Column 13.

The values shown where corresponding figures are given in Column 8 were derived by the following equation:

$$T = 21.78\ S\ (V) \qquad (2)$$

where T = Tons per year

S = Specific weight, in pounds of dry solids per cubic foot of deposits in place

V = Volume of deposits in acre-feet per year

The coefficient 21.78 = 43,560 cubic feet per acre-foot ÷ 2,000 pounds per ton.

No attempt has been made to recompute the Stabler data (21), computed and published by Stevens (22), or other similar computations already published. It is believed that, in some cases, the usefulness of short-term suspended-load records could be improved by the method proposed by Johnson (15).

Column 10.—The specific weight has been estimated in all cases (except Record 74) from comparison of the character of deposits, extent of reservoir drawdown, etc., with similar characteristics in reservoirs where average specific weight has been determined (16).

Column 11.--Sediment concentration in runoff was computed by the equation:

$$S_c = \frac{S_t}{1359\ (R)} \qquad (3)$$

where S_c = Sediment concentration in percent

S_t = Sediment load in tons

R = Runoff in acre-feet

1359 = Weight of one acre-foot of sediment-free water, in tons

The concentration as thus derived is: Weight of dry sediment ÷ weight of a volume of pure water equal to the volume of sediment-water runoff.

The preferred method of expressing sediment concentration for individual samples is: Weight of dry sediment ÷ total weight of the sediment and water in sample. Up to 5 percent concentration, there is an insignificant difference between the two methods, but the 59 percent concentration reported subsequently for a sample from the James River would be 70 percent by the method used to compute Column 11.

Column 12.—These data are obtained by dividing figures in Column 9 by figures in Column 3.

Column 13.—The estimates in this column are for the long-term average annual sediment load under existing conditions of lands use and river development. They represent simply the writer's judgment based on consideration of the following factors:

1. Relation of runoff during the period of sediment record to the long-term trend of runoff. This factor is discussed at some length in a subsequent section. The occurrence or absence of unusual flood flows during the period of sampling has also been taken into account.

2. In using reservoir sedimentation records, losses of sediment over the spillway or through outlets, and deposits above spillway crest have been taken into account. The percentage of sediment trapped has been estimated from curves previously published (5).

3. In using suspended-load records an allowance has been made for bed load.

4. The method of sample analysis and computation of suspended-load records has been considered, and is discussed in a subsequent section.

5. Changes in land use, the extent of watershed-cover deterioration, and similar factors have been taken into account in a minor way when old records were considered.

Where no reasonable basis could be found for a quantitative estimate, letter designations have been used to indicate that, in the writer's judgment, the value in Column 12 is very low (VL), low (L), approximately correct (A), high (H), or very high (VH).

ACCURACY OF SUSPENDED-LOAD DATA

Many of the records[1/] based on suspended-load sampling were computed in a manner that gives a systematic error in the direction of underestimation. In the records reported by Stabler (21) and computed by Stevens (22) samples were collected almost daily, but were combined in approximately equal proportions at intervals of about 10 days, more or less, and the composite sample was analyzed. The percent of sediment by weight in the sample and the average discharge for the corresponding period were then used to compute the average daily suspended load. In other cases, only a few samples per month were collected and, although analyzed separately, the average concentration and the average discharge for the month were used to compute the monthly sediment load. Both of these methods are based on arithmetical averaging and fail to give proper weight to the larger loads carried during periods of higher discharge.

Love (18) has shown that very large proportions of the total annual suspended load of small streams are carried during a few days out of the year. The same principle applies to larger streams although the proportions are not so pronounced. For example, during the month

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1/ Records 1, 2a, 2b, 3, 4a, 4b, 18, 19a, 20, 21, 22a, 23, 25a, 26, 30, 34, 40a, 41a, 63b (in part), 65, 66, 67, 68, 70, 72, 73 and 75.

of September 1939, the suspended load of the Colorado River at Grand Canyon, Ariz. (24), calculated from daily sample concentrations and daily discharge, was 21,279,000 tons. If the daily concentrations are averaged for 10-day periods and multiplied by the discharge of these periods (in tons), the total load is calculated as 18,672,000 tons. If the daily concentrations are averaged for the entire 30 days, the total load is calculated as 15,199,000 tons.

Table 2 gives comparative data from suspended-load records reported by Stevens (22) or Fortier and Blaney (10), which were obtained from composited samples or average concentrations, and later records of longer duration for the same area, which are based on daily weighting of suspended load or on reservoir sedimentation. This table shows ratios between earlier and later records of 1:0.58 to 1:12.2, averaging 1:2.46 for sediment loads, and 1:1.7 to 1:10.3, averaging 1:3.27 for sediment concentration in runoff. Similar comparisons have been made for other sections of the country which show a greater range, but about the same average difference. These differences have been taken into account, but not on any uniform basis, along with other factors, in estimating the long-term average sediment production.

Recent experimental work on sediment samplers at the Iowa Institute for Hydraulic Research, and subsequent field tests of scientifically designed samplers, reported by Benedict (1a) indicate the possibility that sediment concentrations obtained by bottle samplers on Western streams average too low. While Benedict's conclusions were presented "as of a tentative nature" they show that "The average sediment concentration in the samples collected with the US D-43 sampler was . . . higher than in those collected with the Colorado River sampler, the percent difference varying with the stream velocity and the size of the sediment in suspension". Table 3 shows the results of field tests.

Table 3.--Percent difference in concentration of samples collected with the US D-43 sampler as compared with those collected with the Colorado River sampler.

Station	Sets of samples	Percent difference		
		Minimum	Maximum	Average
San Juan River at Farmington	1	-	-	+33
Animas River at Farmington	1	-	-	+29
Green River at Green River	3	0	+8	+5
Colorado River near Cisco	4	+3	+14	+8
San Juan River near Bluff	6	+26	+71	+46

Tests are not yet sufficiently extensive or conclusive to warrant any allowance being made for this factor in estimates of long-term sediment production. It should be recognized, however, that this factor would tend to make the estimates conservative where they are based on suspended load records.

Table 2.—Comparison of sediment records for the same areas

Station	Record number	Runoff per sq.mi. during period	Sediment per sq.mi. during period	Sediment concentration in runoff	Ratio of sediment production	Ratio of sediment concentration
		Acre-feet	Tons	Percent		
*Green River, Green River, Utah	19a	92	207	0.165	1:2.86	1:3
Green River, Green River, Utha	19b	87	592	.499		
*Colorado River, Cisco, Utah	22a	190	378	.146	1:1.98	1:1.84
Colorado River, Cisco, Utah	22b	205	749	.269		
*San Juan River, Bluff, Utah	25a	110	696	.46	1:2.67	1:3.78
San Juan River, Bluff, Utah	25b	79	1,861	1.74		
*Little Colorado River, Woodruff, Ariz.	30	11	113	.732	1:12.2	1:10.3
Little Colorado River Area	32b	13	1,380	7.55		
*Gila River, San Carlos, Ariz.	40a	20	133	.49	1:5.2	1:4.8
Gila River, San Carlos Reservoir	40b	21	690	2.364		
*Salt River, Roosevelt, Ariz.	41a	434	2,031	.344	1:0.58	1:1.7
Salt River, Roosevelt Reservoir	41b	145	1,170	.59		
*Verde River, McDowell, Ariz.	42a	124	154	.092	1:3.27+	1:6.9+
Verde River, Bartlett Reservoir	42b	58	504+	.637+		
*Pecos River, Santa Rosa, N. Mex.	73	60	540	.663	1:1.94	1:2.48
Pecos River, Alamogordo Reservoir	74	47	1,046	1.643		
*Pecos River, Dayton, N. Mex.	75	25	203	.591	1:0.9+	1:1.4+
Pecos River, Lake McMillan	76	16	183+	.832+		
Average (Geometric Mean)					1:2.46	1:3.27

*These records are based on composited suspended-load samples or on use of average concentrations and average discharge.

In the order of relative accuracy the suspended load records may be classified into three groups. Group 1, the most accurate, includes records 19b, 22b, 24a, 25a, 27-29 and 32a. Group 2 includes records 33, 45-57, and 59-63. Group 3, the least accurate includes records 1-4, 18, 19a, 20-22a, 23, 25a, 26, 30, 34, 40a, 41a, 42a, 65-68, 70, 72, 73, and 75. Data are not sufficient to estimate the probable average limits of accuracy for any group, but the tests that are now underway on methods of sampling should allow further evaluation of at least the records in Group 1. From indications now available, it appears that all suspended load records, even those in Group 1, may be biased on the low side by reason of method of sampling as well as insufficient frequency of sampling. In the Southwestern states, on an average, the long-term total sediment load should be greater than the reported suspended load by (a) a factor to correct for bias in method of sampling (b) a factor to correct for bias in frequency of sampling and method of computation (c) a factor for additional unmeasured bedload, and (d) in many records, a factor to correct for subnormal run-off during the sampling period.

ACCURACY OF RESERVOIR SEDIMENTATION DATA

Tests have been made in 10 detailed reservoir surveys by the Soil Conservation Service for limits of error in capacity and sediment volume determination. Each of these surveys was made by both the range and contour methods described by Eakin and Brown. (7) The maximum difference obtained was less than 4 percent and the average difference was less than 1 percent.

The accuracy of reservoir reconnaissance surveys has been statistically tested by comparison with detailed surveys of the same reservoirs. The test consisted of 50 samples in which many varieties of reconnaissance methods were used. The results showed that, regardless of the methods used, 80 percent of reconnaissance surveys will give an annual sediment accumulation within 30 percent, plus or minus, of the correct value, while 20 percent will show an error of 30 to a maximum of 75 percent. The errors were equally distributed between plus and minus values. The tests also showed a correlation in accuracy between certain methods of survey and certain types of reservoirs.

Instructions for making reconnaissance surveys, based on these tests, have been prepared by the Soil Conservation Service. A specialist in these surveys should be able to measure sediment volume within 10 percent in 80 percent of the reservoirs on which reconnaissance surveys are made, and the maximum error should not exceed 30 percent. The accuracy represented by the reconnaissance surveys listed in Table 1 probably lies somewhere between the limits shown by the test of 50 samples and the standards which the most skilled operator could obtain.

The accuracy of reconnaissance surveys increases with the number of observations taken, but the whole purpose of these surveys is to obtain rapidly an approximate measurement of the extent of sedimentation. Time allowance for surveys generally ranges from one-half day for ponds to three days for reservoirs of several hundred thousand acre-feet.

By way of example, a reconnaissance survey of Lake Corpus Christi on the Nueces River, Texas, consisted of 45 sediment measurements made by one man in two days. No accurate original capacity figure was available as no contour maps other than the U.S.G.S. topographic quadrangle on a scale of 1:62,500 covered the reservoir area. The capacity estimated from this map by consulting engineers at the time of construction was 66,000 acre-feet.

From measurements made in the reconnaissance survey an original capacity of 63,536 acre-feet, an existing capacity of 50,061 acre-feet, and a sediment volume of 13,475 acre-feet were estimated. The annual capacity loss was estimated at 3.12 percent.

The subsequent detailed survey took 4 months time of a five-man survey party. The lake was surveyed by both the contour and range method. A total of 1,879 sediment measurements were made. The original capacity was computed to be 53,955 acre-feet by the range method and 52,672 acre-feet by the contour method, while the annual sediment deposited was computed as 1,387 and 1,426 acre-feet, respectively. Using the range method as a standard, the contour method gave a sediment volume 2.8 percent higher, but the reconnaissance survey gave a sediment volume 30.0 percent higher. It is significant, however, that if the annual rate of loss estimated in the reconnaissance were applied to the correct original capacity, the estimated annual sedimentation would be only 21.3 percent too high. It has been found frequently true that much of the error occurring in reconnaissance surveys results from erroneous original capacity figures obtained from reservoir owners or original maps.

An error may also result in converting measured volumes of sediment to tonnage on the basis of an estimated average specific weight. The estimated specific weights in Table 1 should be within 10 pounds per cubic foot of the correct average. The percentage difference decreases with increasing weight. One acre-foot of sediment, at 60 pounds per cubic foot, weighs 20 percent more than one acre-foot at 50 pounds, and one acre-foot at 95 pounds weighs 11.1 percent more than one acre-foot at 85 pounds.

COMPARATIVE VALUE OF SUSPENDED LOAD AND RESERVOIR SEDIMENTATION RECORDS

The most accurate measure that can be obtained of total sediment production from a drainage area is by a detailed reservoir sedimentation survey in which (a) the sediment losses over spillway or through outlets are negligible or measured (b) above-crest deposits, if any, are measured,

(c) the average specific weight is accurately determined from numerous samples of deposits, and (d) the period of accumulation is at least 10 years.

The detailed reservoir survey data in the Southwestern States are generally on a par with Group 1 suspended load records, because in no case are all of the above conditions fulfilled by any reservoir survey, whereas suspended load records are subject to the limitations previously set forth. There is a difference, however, in that the suspended load records are almost always less than the long-term total load, whereas the reservoir records may indicate rates higher or lower than the true average because of estimated specific weight. On the other hand, reservoir records as well as suspended load records generally cover the period of subnormal runoff during the 1930's and therefore tend to be lower than the true long-term average.

Suspended load records in Group 2 and reservoir reconnaissance records may be essentially on a par, but the former are more likely than the latter to be lower than the true long-term average total load. Suspended load records of Group 3 are definitely the poorest of all records with a decided tendency to be far below the true average long-term total load.

LONG-TERM RATES OF SEDIMENT PRODUCTION

It is generally recognized that the Southwest experienced an unusual number of dry years during the late 1920's and the 1930's. With subnormal runoff, subnormal sediment loads are also to be expected. Most of the best sediment records, especially Records 19b, 22b, 25b, and 32a, were obtained during this period. If the best records are to give a framework of rates to which the less adequate records may be related, these records must be adjusted to reflect the probable long-term runoff.

In Southwestern United States sediment production is, by and large, a function of precipitation more than of any other factor. The natural sparsity of vegetation over most of this arid to semi-arid region leads to high rates of erosion during infrequent but often intense rains. The question of acceleration in rates of erosion in this region is highly complex and controversial. There is indisputable evidence of widespread arroyo development since the introduction of cattle raising on a large scale some 60 years ago. Regardless of the uncertain cause-and-effect relationship of overgrazing and arroyo development, these valley trenches have greatly expanded the areas that feed sediment directly into main stream channels, and have themselves been the source of enormous volumes of sediment. Some investigators maintain that rates of sediment production are still increasing as the arroyos continue their headward fingering over the landscape.

No quantitative proof has been developed that sediment loads being transported out of major watersheds are larger now than formerly, or that the rate is increasing. The longer records of sediment load plotted against annual runoff as in Figure 3 fail to disclose any variations with time that might be related to increasing rates of sediment production. However, all of these records have been obtained since the principal land use changes by overgrazing and deforestation occurred. Furthermore, such measures as increasing irrigation diversion of river water with its silt load, water spreading, revegetation of ranges, silt-control barriers, bank protection, etc. tend to counter and obscure possible increases in sediment production from watershed deterioration. For these reasons no allowances are made in the estimates presented here for changes in sediment rates as a result of changes in land use or treatment.

Annual runoff for years prior to stream gaging, back to 1850 or earlier, have been estimated for at least three western streams. La Rue (17) published a hydrograph of flow of the Colorado River at Lees Ferry, Ariz., beginning with 1850. For the years 1850 through 1896, his estimates were based on the levels of Great Salt Lake, recorded since 1875, and reconstructed from traditional evidence from 1850 to 1875. La Rue found that the greatest variation in the curve of relationship between lake levels and measured discharge at Lees Ferry was 29 percent for 1908. In three other years the variation was more than 20 percent. In 16 out of 28 years, however, the variation was less than 10 percent. La Rue "recognized that estimates so made may be considerably in error for any single year, especially prior to 1875, but it is believed that they are sufficiently reliable to indicate in a general way the periods of high and low runoff from the upper basin of the Colorado".

La Rue (17), Debler (6), and Tipton (23) have estimated the flow at Lees Ferry from 1897 through 1921 by proportioning upstream and downstream recorded runoff. Debler's estimates show an average annual flow for this period, of 15,857,000 acre-feet; La Rue's estimates show 15,370,000 acre-feet, or 3.1 percent less; and Tipton's estimates show 15,588,000 acre-feet, or 1.7 percent less. For individual years, La Rue's estimates are as much as 13.4 percent higher and 11.1 percent lower than Debler's, whereas Tipton's estimates run as much as 7.7 percent higher and 8.4 percent lower than Debler's. As Debler's report contains data more nearly fitted to the present analysis, his estimates have been used in computing the probable long-term suspended-sediment load at Grand Canyon. Only a negligible difference would result, however, if the La Rue or Tipton estimates were used instead.

Hardman and Venstrom (12) have made estimates of the flow of the Truckee River from 1840 through 1939, based on a precipitation index for various weather stations in the Sierra Nevada, and on fluctuation of water level in Pyramid and Winnemuca Lakes.

An unpublished report on the U. S. Department of Agriculture Flood Control Survey of the Rio Puerco, New Mexico (25) contains a hydrograph, of the annual flow of the Rio Grande at San Marcial, N. Mex., since 1850. This is based on a precipitation index for Sante Fe.

Figure 2, based on the studies just described, shows the cumulative departure in percentage from the mean runoff since 1850 for the Truckee at the California-Nevada state line, the Colorado at Lees Ferry, Ariz., and the Rio Grande at San Marcial, N. Mex. This graph clearly shows that the more reliable suspended-load records were obtained in a period when the departure curves were falling rapidly and almost continuously, and runoff was, therefore, below the estimated 90-year mean.

The annual suspended load for Records 19b, 22b, 24a, 25b, and 32b has been plotted against annual runoff on logarithmic paper, as shown in Figure 3. Reasonably good correlation following an exponential relationship is indicated. The curves are defined by an equation of the form:

$$S = cR^x$$

where S = Annual suspended sediment

R = Annual runoff

c = Coefficient

x = Exponent

Using the recorded data from Record 32a, this equation was found by the method of least squares to contain the values

$$S = 0.00295R^{1.52}$$

The curve of this equation is plotted as Curve 1 in Figure 3. Curves 2, 3, and 4 were drawn "by eye". As the exponent is greater than 1 in all cases, the suspended load is shown to increase at a greater rate than runoff. In other words, the larger the annual runoff, the higher is the mean annual sediment concentration.

Curve 3 of the data from Green River, Green River, Utah, is the steepest of the four and, therefore, the concentration increases at the greatest rate. The fact that during the period of sediment record at Green River, 1930-41, the runoff was more deficient compared with the long-term average than at any other station in the Colorado Basin, explains the larger difference shown in Table 1 between measured and estimated long-term average load. Curve 4 of the record on the Colorado at Cisco, Utah, is also steeper than Curve 1, the Grand Canyon record, but the difference in runoff during the period of record and the long-term average is not so great as for Green River. Curve 2 of the record on the San Juan River at Bluff, Utah, is less steep than Curve 1, and also shows a greater spread of points, reflecting, it is thought, the more important effects of erratic summer cloudburst storms

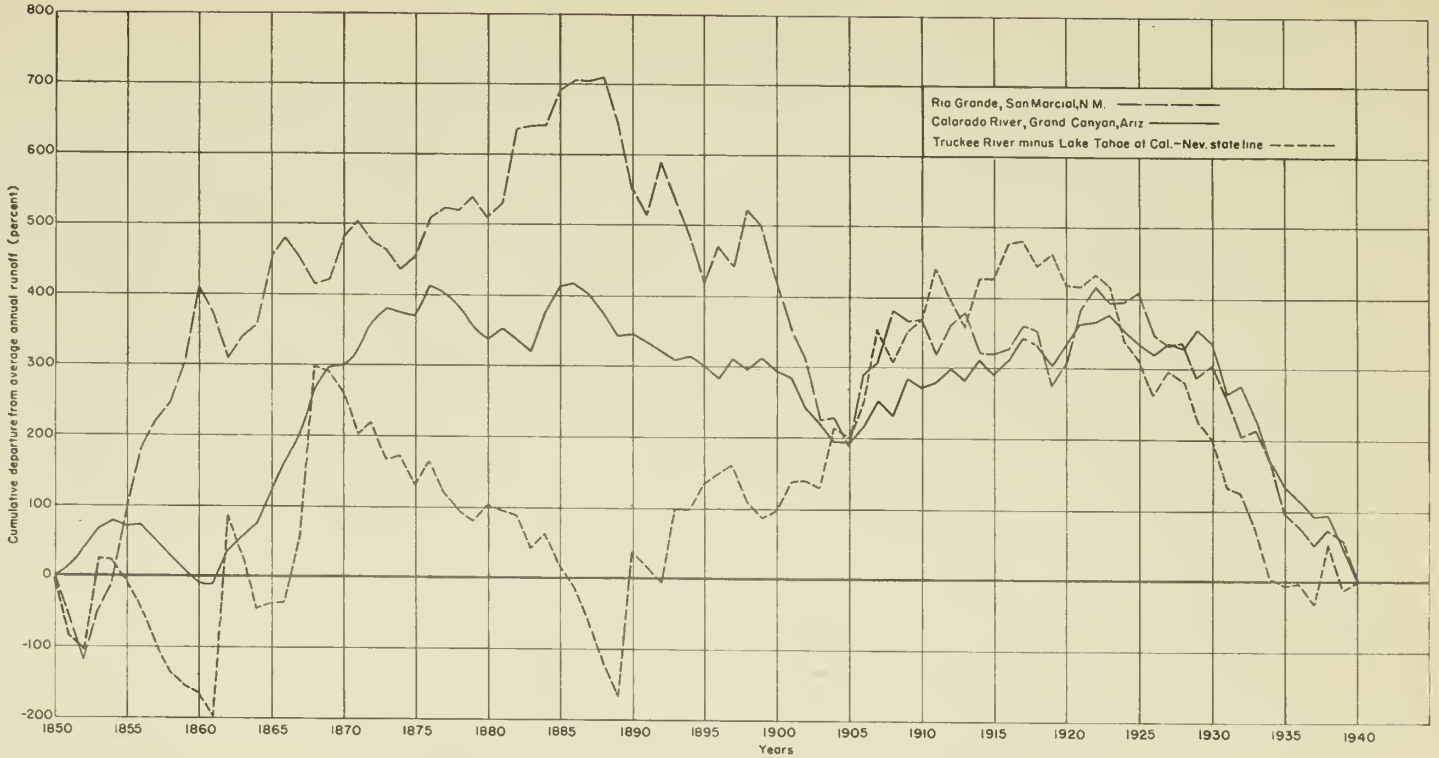

Figure 2 Cumulative departure from average annual runoff of Rio Grande, Colorado, and Truckee Rivers 1850–1940.

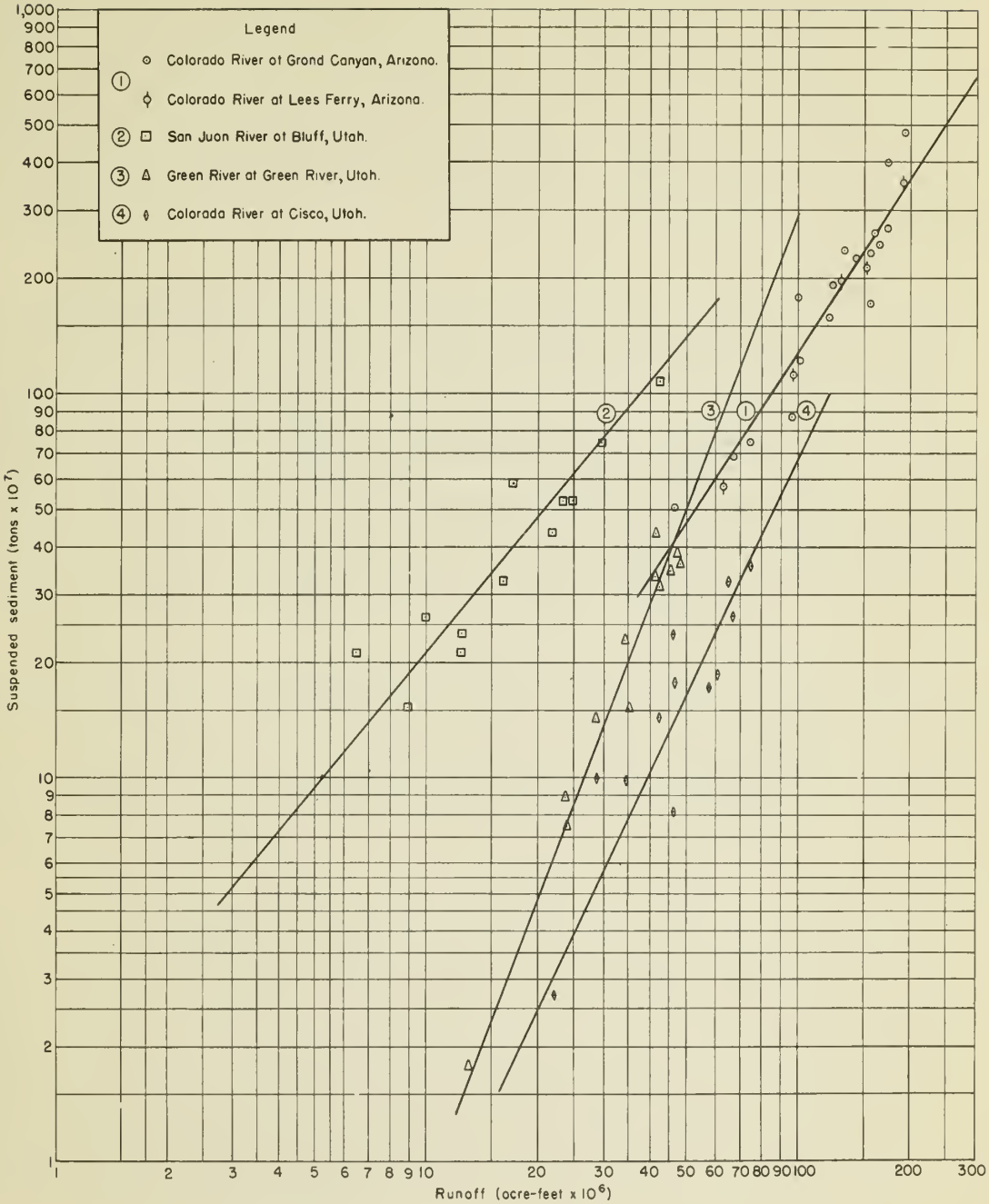

Figure 3.-Relation of annual runoff and suspended sediment load of the Colorado River and tributories.

in the highly erodible country of the lower San Juan Basin.

The scatter of points in the 45-year Record 63b of the Rio Grande at San Marcial, N. Mex., shown in Figure 4, is so great that only curves showing the general trend are warranted. This scatter is believed to result in part from fortuitous summer storms in arid, highly erodible drainage areas of the Rio Puerco and Rio Salado and, in part, from conditions in the long aggrading valley of the Rio Grande above San Marcial. Often in high flood years large quantities of sediment are deposited on the alluvial flood plain, while movement of sediment down the channel is quite erratic. The envelope curves reflect a similar tendency, however, for sediment concentration to increase with increase in runoff.

The long-term runoff for Records 19b, 22b, 25b, and 32a, was estimated by taking the annual runoff estimated or quoted by Debler (6) from 1897 until the beginning of the sediment record and reading the value for annual suspended load from the curves in Figure 3. In the case of Record 25b, Debler's estimates were for the San Juan River at Farmington, N. Mex. Records of annual flow at Farmington were plotted against annual flow at Bluff and from the fairly good curve of relationship, the estimated runoff at Bluff was used in the same manner. In each of these records, therefore, a 45-year period forms the basis of estimating the long-term suspended load. In each case the suspended load was estimated to be 95 percent of the total load. Actually the percentage of bed load may be somewhat higher at some stations.

The estimated mean annual flow of the Colorado at Lees Ferry for the 90-year period, 1851-1940, is about 1,000,000 acre-feet larger than for the period 1897-1941 which is used in the present analysis. Therefore, the estimated long-term mean is conservative if credence is given to hydrographs extending back to 1850, and to the theory, which has been advanced by some hydrologists, that 90 years represents a secular cycle in precipitation.

Some investigators (11, 12) have concluded, however, from studies of the fluctuations in levels of lakes in the Great Basin that the period from about 1860 to 1915 or 1917 was exceptionally wet, and that the lakes rose to higher levels than in the preceding 100 years. S. T. Harding (11) in 1935 concluded that lake level and tree-ring records gave "more indication of a tendency toward increase in moisture over the last 300 years than there is toward a decrease". Therefore, it would seem that a record from 1897 to 1940 would nearly balance 21 years of relatively wet period against 23 years of relatively dry period, and so strike a long-term average as reasonable as can be obtained from existing data.

In estimating long-term rates of sediment production in the Rio Grande drainage basin, a somewhat different method of approach was used. The suspended load passing San Marcial has been measured, or estimated with fair accuracy, since 1897. Bed load is estimated to represent 15 percent of the total load at San Marcial, and this addition to the computed suspended load gives a figure of, roughly, 26,000,000 tons as the average annual total load at this station.

This percentage addition for bed load is believed to be conservative in view of the reported depths of channel-bed scour during high flows. Happ (13a) has estimated that, in general, the bed scour goes down at least as much as the water level rises during floods, and perhaps much more during prolonged flows. He reports that during the relatively large and prolonged spring flood of 1941 (maximum discharge about 25,000 second-feet) cross-sections sounded at the Bernalillo and San Acacia gaging stations and Highway 66 and Pueblitos bridges indicated scour of a magnitude that, if applied to the entire river, would involve movement of something like 50,000 acre-feet of material, chiefly sand, from the river bed. The suspended load passing San Marcial in May and June 1941 was 5,653 acre-feet (at 86 pounds per cubic foot).

The estimated total load for San Marcial also tends to be conservative, as the period 1850-1940 shows a larger annual flow than the period 1897-1940, in harmony with the Colorado.

The estimated 26,000,000-ton annual load was distributed back to principal tributaries on the basis of the best available data from suspended-load measurements, survey of sediment accumulation in the Middle Valley, and heavy mineral studies of sources of channel and floodway sand deposits. The estimates made in this connection are discussed more fully under the subsequent heading "Rio Grande".

In making estimates of long-term sediment production for other watersheds, the writer has taken a conservative point of view, and the estimates should be interpreted as a minimum reasonable figure for use in design.

REGIONAL CHARACTERISTICS

Certain general notes and deductions can be given concerning the major drainage regions considered in this publication.

GREAT BASIN

(1) In the higher parts of the mountain ranges bordering the Great Basin — The Sierra Nevada on the west and the Wasatch Mountains and Colorado Plateau on the east -- where precipitation is above 25 inches with a substantial percentage falling as snow, and if the native forest cover is in good condition, rates of sediment production are relatively low. This is indicated by records 2, 3, and 15. Generally, an allowance of 100 to 200 tons/sq. mile annually for total load should be adequate.

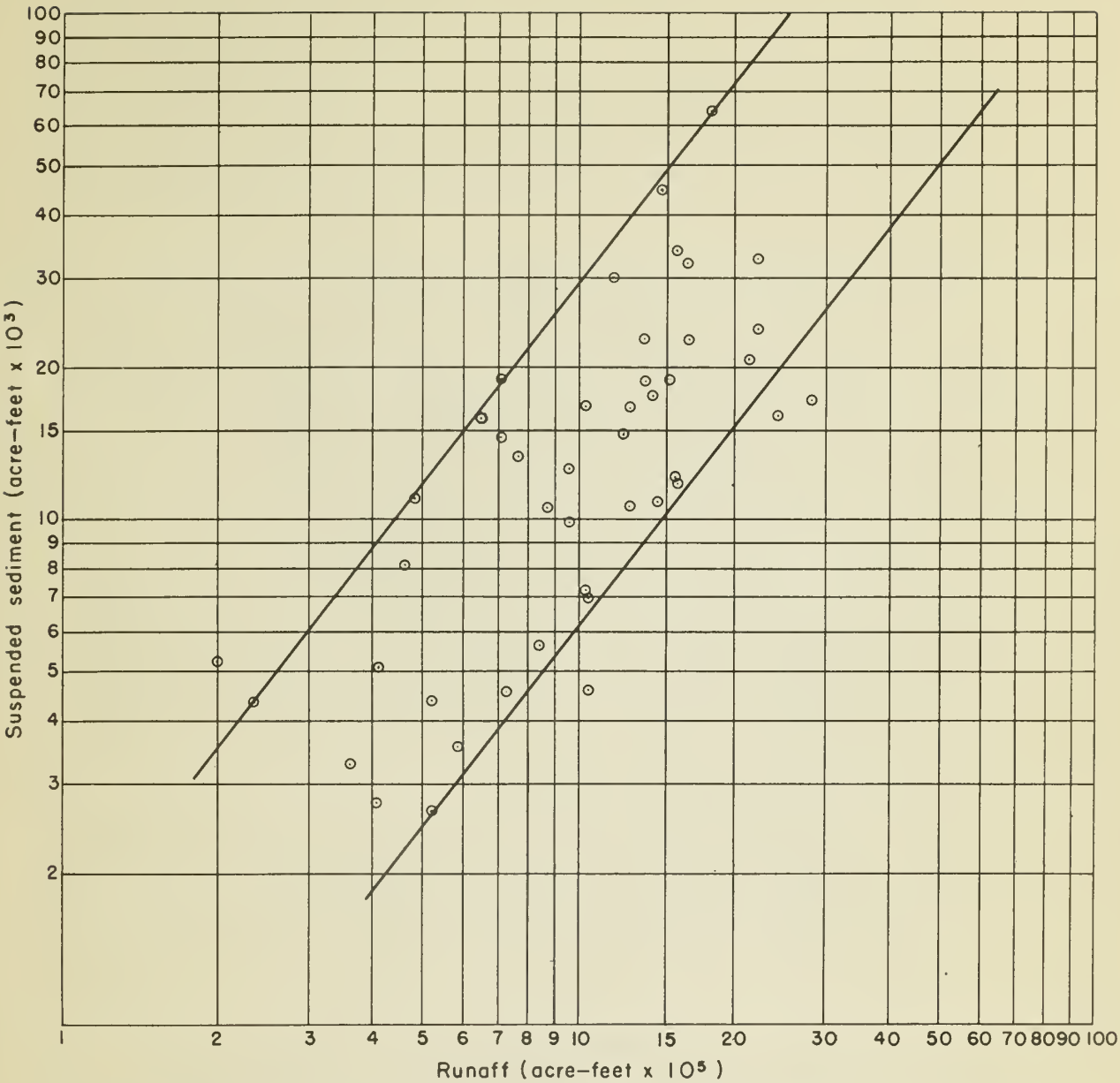

Figure 4.— Relation of annual runoff and suspended sediment load of the Rio Grande, at San Marcial, New Mexico, 1897-1941

(2) Along the margins of the Southern California coastal ranges—the San Gabriels, San Bernadinos, etc.—long-term rates of sediment production are much higher because (a) slopes are exceptionally steep, and the thin soil mantle is inherently unstable (b) with less precipitation, vegetal cover is not so good and the soil is less protected from erosion, and (c) occasional high intensity storms produce excessive runoff, channel and gully erosion. Records 9 and 10 are typical. Along the margins of these mountains, long-term rates of 1,000-1,500 tons/sq.mile annually should be assumed, and allowance made for 10,000-15,000 tons/sq.mile in exceptional storms like that of March 2, 1938.

(3) High rates of sediment production should be assumed along the base of the Wasatch, Colorado Plateaus, and some intrabasin ranges subject to summer cloudburst storms. Records 16 to 17 are representative. Even higher rates were indicated, however, by measurement of deposits on fans of mountain canyons in the Sevier River watershed, Utah, and by records of sedimentation behind debris barriers, obtained in connection with the U. S. Dept. of Agriculture Flood Control Survey. Annual rates in this area are reported to be related to the extent of watershed cover deterioration. Typical are Pinto Creek (133 sq. miles, estimated 50-year accumulation on the fan) 1,666 tons/sq. mile annually, and Coal Creek, near Cedar City, Utah, (94 sq. miles, estimated 40-year accumulation on the fan) 4,258 tons/sq. mile annually. Extreme limits estimated from fan surveys were 740 to 14,255 tons/sq. mile annually, but the highest rate was attributed to recent landslides. Individual floods in 1935 and 1936 deposited in debris basins 1,300-7,000 tons/sq. mile. In the lower part of mountain canyons, rates of 1,500-3,000 tons/sq. mile annually should be assumed and allowance made for rates up to 5,000-10,000 tons/sq. mile or more in individual storms.

(4) Whereas the ephemeral streams that are lost after leaving the mountains deposit most of their load on their fans, some permanent streams appear to acquire larger loads during their course through intermountain valleys despite sediment loss by diversion of water for irrigation. This is indicated by comparison of Record 13 from Piute Reservoir in the upper part of Sevier River Valley with Record 11 from Sevier Bridge Reservoir in the lower part of the valley.

(5) Stream loads away from the eastern and western margins of the Great Basin appear to be materially smaller both in terms of sediment concentration and in sediment production per square mile. Representative records 1, 5, 6, 7 and 8 indicate long-term rates on the order of 100-300 tons/sq. mile. Lower rates are partly due to diversion of water for irrigation, and partly to the relatively low runoff and uncommon floods in this region.

COLORADO RIVER

(1) None of the existing records on the Colorado River below Boulder Dam or in the Imperial Valley are given, because desilting of the river by Lake Mead has made all measurements prior to 1935 inapplicable. The U. S. Bureau of Reclamation is conducting extensive studies of retrogression in the river channel below Boulder Dam and Parker Dam. Information on sediment movement in the lower Colorado may be obtained from the Denver office of the Bureau.

(2) Records 19b, 22b, 24a, 25b, and 32a, obtained by the U. S. Geological Survey represent probably the best long-term suspended-load data collected in the United States. The relation between annual runoff and suspended load at these stations, and the relation of annual runoff during the sampling period to annual runoff from 1897 through 1941, as previously described, have been used to compute long-term sediment production. The suspended load has been assumed to be 95 percent of the total load in each of these records. The long-term rates thus derived are believed to be conservative, because hydrographs (Figure 1) indicate a still larger long-term runoff for the 90-year period from 1850, and the assumed bedload factor is not high. Furthermore, the most recent evidence indicates the possibility of a systematic underestimation of suspended load from the type of sampler used in the collection of these records (1a).

(3) It seems certain that the one-year or shorter records, 18, 19a, 20, 21, 22a, 23, 25a, 26, and 30 indicate rates far too low for the reasons previously given.

(4) Records 28 and 29 on smaller watersheds at Mexican Springs, N. Mex., in the San Juan River Basin, include samples of runoff from certain intense local storms in 1941. The sediment production, especially in Record 29, is too high for even this area where rates of production are limited only by the amount and intensity of precipitation. Precipitation during the period of sampling in Record 27 was close to "normal" as judged by the 92-year record at Santa Fe. This precipitation index has been used to estimate long-term runoff rates from curves published by Harrold (13) and the measured sediment concentration has been assumed to estimate the long-term rates.

(5) Branch (3) estimated that the Williams River had an average silt yield of 1,800 acre-feet from a 5,300-square-mile drainage area. This would be 629 T./sq. mile at 85 pounds per cubic foot, compared with 1157 T./sq.mile estimated from reconnaissance sedimentation survey of part of Lake Havasu in May 1941. The long-term average is believed to lie between these figures.

(6) It is obviously difficult to generalize on rates of sediment production in a drainage basin so large and varied in topography, geology, soils, and climate as the Colorado. In general, it may be said that rates increase from higher elevations to lower elevations and from the headwater areas downstream.

In the Utah portion of the Green rates are on the order of 1,500-3,500 T./sq. mile. In the mountainous portions of the upper Colorado, rates may be as low as 100 T./sq. mile for large parts of well forested areas and negligible for small areas; in the middle section the Colorado may transport about 500 T./sq. mile. The load reaches an estimated long-term average of 1,300 T./sq. mile at the junction with the Green.

The more barren portions of the Colorado Plateaus yield the greatest sediment loads in the drainage basin. The San Juan and Little Colorado have long been noted as rivers of mud during summer cloudburst runoff. The San Juan and streams entering the Colorado from the northwest between the mouth of the Green and Lees Ferry, Ariz. have the highest sediment production of any part of the basin. Long-term rates are on the order of 3,000-4,000 T./sq. mile, but may be 6,000-8,000 T./sq. mile for smaller areas. Furthermore, sediment concentration in runoff, when computed from net gains in flow between the Green-Upper Colorado-San Juan and Lees Ferry or Lees Ferry and Grand Canyon, shows the astonishingly high averages of 8.52 and 7.55 percent. The upper Virgin River had an equally high sediment production average for the 2 years, 1936 and 1941 of 3,410 T./sq. mile, but the concentration was much less, only 1.73 percent. The Little Colorado section does not have quite so high a production because of greater aridity and less runoff per unit area, but the indicated average concentration in runoff is very high--7.55 percent. The Zuni watershed near the headwaters has a higher average runoff and a higher sediment production, but a lower concentration. Obviously, Record 30 is entirely out of line with known characteristics of the Little Colorado Basin.

GILA RIVER

(1) Estimates of sediment production have been made for various subdivisions of the Gila River Drainage Basin above San Carlos Reservoir in the course of a Flood Control Survey by the U. S. Department of Agriculture. (26) These estimates are based on erosion surveys, measurements of the rate of arroyo trenching and bank erosion, suspended-load measurements, stock tank surveys and analysis of reservoir surveys and runoff characteristics. Table 4 gives the conclusions of field engineers on present rates of sediment production with estimated long-term rates of runoff.

Table 4.—Estimated sediment production in the Upper Gila River Watershed

Subdivision	Drainage area	Estimated annual runoff	Estimated sediment concentration by volume	Estimated annual sediment load 1/
	Sq. miles	A.F./sq.mile	Percent	T./sq.mile
Headwaters	2,000	64	0.5	518
San Francisco	2,750	69	.7	737
Cliff-Gila	850	46	1.3	933
Duncan	1,250	39	4.4	2,732
Eagle-Bonita	1,000	53	.7	594
San Simon	2,200	6.8	10.5	1,137
Safford	1,700	18	4.8	1,381
San Carlos	1,150	33	1.9	1,008

1/ at 70 lbs./cu.ft.

(2) The long-term rate of silting of San Carlos Reservoir under present conditions of river development and land use has been variously estimated from 5,000 to 10,800 acre-feet annually, or (at 70 lbs./cu.ft.) from 592 to 1,278 T./sq. mile. The long-term estimated given in Table 1 is based on application of the sediment concentration 2.364% to the 46-year runoff (1895-1940) of 360,000 A.F. This rate would indicate an average annual sedimentation in the reservoir of 7586 A.F. The U. S. Army Engineers have estimated, however, that the annual runoff for the 74-year period (June 1867-June 1941) was 403,000 A.F. If this figure were used the sediment production rate would be 1005 T./sq. mile and the sediment deposited in the reservoir 8492 A.F. annually. These figures do not take into account the higher average concentrations that may exist with larger long-term runoff, as indicated by the Colorado River records.

(3) In a study of erosion and sedimentation in the Hot Springs, Wide Hollow and Eden Spring Washes near Eden, Ariz. (T. 5-6 S., R. 24-25 E.), made in connection with a flood control survey by the U. S. Dept. of Agriculture (26), survey specialists estimated the long term annual sediment production from the 18.53 sq. mile drainage area of these washes as 20.8 A.F., of which 8.16 A.F. was estimated to be silt and finer material. At 85 lbs./cu. ft. this is equivalent to a sediment production of 2078 T./sq. mile annually.

(4) Fortier and Blaney (10) give various fragmentary suspended-load records on the Gila and these have formed the basis for different estimates of the sediment load of the Gila at its mouth. The U. S. Bureau of Reclamation has used figures for the lower Gila (D.A. 57,000 sq. miles) as follows: Annual runoff 1,070,000 A.F., or 19 A.F./sq. mile. Sediment 15,000 A.F. which

at 85 lbs./cu.ft., equals 487 T./sq. mile. Bonner (2 p.309) using the same data, excluding the area above Roosevelt Dam, gives the drainage area as 52,340 sq. miles and sediment as 16,000 acre-feet, which at 85 lbs./cu.ft., equals 566 T./sq. mile. No data are available on the sediment load of the lower Gila since construction of San Carlos Reservoir and other storage and diversion works.

(5) The high sediment content of many Arizona streams has been widely recognized. An anonomous source (1) reports that the San Pedro water is sometimes as much as 25 percent silt, so thick it will scarcely run.. It has carried 15,000 cubic yards daily into canals and laterals. The total silt discharge was estimated at 2,000 acre-feet annually from the 4480-sq. mile drainage area, according to C. J. Moody. This would be equivalent to 826 T./ sq. mile at 85 lbs./cu.ft.

RIO GRANDE

(1) The suspended-load data reported in Records 45 through 57 and 59 through 63 were collected by the Albuquerque, N. Mex., Regional Office of the Soil Conservation Service from 1936 to 1941 and since that date by the District Engineer Office, Corps of Engineers, U. S. Army. The work of both agencies was largely under the supervision of Herbert W. Yeo. More than 13000 water samples were collected and analyzed during the years 1936-1940. Discharge in Records 47, 47-1, 47-2, 49, 55, 56, 59, 60, 61, 62 and 63 is from U. S. Geological Survey gaging stations, but in several cases preliminary data were used in computations, and the final discharge data published in U.S.G.S. Water-Supply Papers are slightly different. Where no gaging stations exist, the discharge was estimated at time of sampling from float measurements and occasional current meter observations. In addition to the records reported here, fragmentary data are available for more than 200 additional streams or river stations. Records of more than one year's duration on the Rio Grande at San Filipe, Bernalillo, Atrisco, Barelas, Isleta, Los Lunas, Belen, and Bosque, show values intermediate between those of stations upstream and downstream which have longer records.

During the period March 1937 through September 1940 duplicate samples were taken, generally by the same observer, at the San Marcial station. One sample was sent to the Soil Conservation Service and the other to the International Boundary Commission. Although using different methods of analysis and computation the total suspended load computed for the period by the two agencies differed by only 1.6 percent, the SCS record being the higher.

The following notes from the SCS sampling records are of interest. Rio Grande: Maximum sediment content 17.27 percent by weight at San Acacia during flow of 490 second-feet. Rio Puerco: Maximum sediment content 52 percent by weight. During one flood flow 136,000 tons passed Rio Puerco Station in one hour. Highest sediment concentration found in 13,000 samples: 59 percent by weight on Jemez River south of

Pueblo Zia. These percentages are the weight of dry sediment in sample divided by weight of sediment-water mixture in the sample container.

The samples collected by the SCS, except at San Marcial, were unfortunately taken in 16-ounce wide-mouth bottles, which did not allow proper depth-integration, and at most places the samples were taken at only one point in the cross section. Except on the Rio Grande, most of the sampling was intermittent and some important flows were doubtless missed. Furthermore, the discharge was generally estimated. The records tend to show less than the actual total suspended load, and, of course, include no allowance for bed load.

Based on sampling for a 2-year comparable period (5/1/37-5/1/39) it has been estimated (13a) that contributions of tributaries to the suspended load of the Rio Grande is as follows: Rio Puerco 61 percent, Upper Rio Grande (above Cochiti) 24 percent, Rio Salado 7 percent, Galisteo Creek 5 percent, Jemez Creek 3 percent.

(2) Methods of sampling and analysis used by the International Boundary Commission have varied. Sampling has been either (1) by lowering a small-neck bottle at one or more points almost to the bottom, thus attempting to secure a vertically-integrated sample, or (2) sampling with three bottles at the surface, at mid-point, and one-sixth distance from each side. The mean of the samples was divided by 0.908 to obtain the mean concentration. During most of the period, a single analysis was made each month from a composite sample obtained by taking an amount from each collected sample in proportion to the river flow represented by this sample. In the last few years each sample as collected has been analyzed. Only the record at San Marcial for recent years includes enough samples to make it reasonably reliable.

(3) In addition to the data on suspended load and reservoir sedimentation in the Rio Grande Drainage Basin, extensive studies of valley and channel sedimentation have been made by the Sedimentation Section, Office of Research, Soil Conservation Service, and by the U. S. Department of Agriculture Flood Control Survey. Happ (13a) has computed from 90 river and valley cross-sections that an average of 12,069 acre-feet of sediment per year accumulated in the Middle Valley during the 5-year period, 1936-41. More than 25 percent of the sediment accumulated in the 133-mile-long floodway constructed through the Middle Valley by the Middle Rio Grande Conservancy District. Nearly 20 percent more was deposited in areas flooded because of levee breaks. The remaining 55 percent was concentrated in the lower 14 miles of the Valley just above Elephant Butte Reservoir.

Many analyses of the Valley sediment deposits showed an average composition of 44 percent sand, 40 percent silt, and 16 percent clay (Wentworth classification). The average specific weight was found to be 86 lbs./cu.ft. On the basis of heavy mineral analyses, Happ estimated that 35 percent of the Valley sediment came from the Rio Puerco, 19 percent from the watershed above Cochiti, 17 percent from minor tributaries, 13 percent from the Rio Salado, 12 percent from

Jemez Creek, 2 percent from Galisteo Creek, and 1 percent from Sante Fe Creek. For Valley sediment alone, these estimates indicate an approximate contribution per year per square mile as follows: Jemez Creek 2,690 tons, Rio Salado 2,050 tons, Rio Puerco 1,300 tons, Sante Fe Creek 990 tons, Galisteo Creek 650 tons, Upper Rio Grande 370 tons. Available evidence indicates that the rate of deposition in the Valley was considerably higher than normal during the period 1936-41 and that in the reservoir lower, owing to extensive stream avulsions.

Mechanical analyses of suspended-load samples at various stations have given the following results (25): Rio Grande at San Acacia, average of 309 samples showed 30.20 percent sand, 25.11 percent silt, and 44.69 percent clay (Bur. Soils classification). At San Marcial, however, the average of 319 samples during the same period showed 6.93 percent sand, 17.66 percent silt, and 75.41 percent clay. This difference is attributed to the valley sedimentation of coarse sediment through river avulsions between these stations, and to the larger proportion of coarse material passing San Marcial as bed load.

(4) The estimated long-term rates of sediment production in the Rio Grande drainage basin above Elephant Butte Dam are based on proration of sediment reaching the reservoir. In making this proration, suspended-load measurements and repeated sedimentation surveys in the Middle Valley have been used as a basis of adjustment. The long-term rate of total sediment load passing San Marcial is estimated at 26,000,000 tons. This is the product of the computed average annual suspended load from 1897 through 1935 plus an allowance of 15 percent of the total load for unmeasured bed load. Suspended load for the period 1936-41 was excluded because river avulsions above San Marcial caused an exceptional deposit in the valley and greatly reduced the load that would normally have gone into the reservoir. Furthermore, this period included several years of subnormal flow and sediment load.

The estimated long-term load is fairly consistent with the deposition in Elephant Butte Reservoir during the period 1915-35. Assuming an average specific weight of 60 pounds per cubic foot, the total deposits below San Marcial, including those above reservoir crest level and estimated losses through the outlets, amount to 25,009,538 tons annually. By using different methods of comparing the suspended load at San Marcial with sediment accumulation in the reservoir, different investigators have arrived at values for specific weight ranging from 51.8 to 70.2. The true value is almost certainly within this range (16, pp. 17-20). At the limits the tonnage would be 21,591,492 and 29,262,002 tons. The use of 60 pounds is practically a median value, and the long-term load (1897-1935) should be somewhat higher than the 1915-35 load.

Valley sedimentation of 12,069 acre-feet annually from 1936 to 1941, at an average specific weight of 86 pounds per cubic foot, equals 22,606,200 tons annually. During the same period, however, the suspended load passing San Marcial was only 10,350,700 tons annually or almost exactly one-half of the 45-year load (1897-1941).

By comparison of rather meager survey data prior to 1936 in the Middle Valley it is estimated that the average deposition since 1897 was approximately two-thirds of that during the 1936-41 period or, roughly, 8,000 acre-feet per year, practically all of the difference being in the area below Socorro. By mineralogical studies previously referred to, the sources of valley deposits have been approximately proportioned between major tributaries. Taking these proportions, established for the 1936-41 period, and suspended-load records for the same period, a system of ratios was developed to distribute the load at San Marcial back through the watershed. This distribution was then converted to estimated long-term tonnage per square mile for each of the areas and stations which were used in the distribution.

It is readily conceded that the value assigned to any particular station or area may be in error by a considerable percentage, because the period 1936-41 was abnormal in both sediment production and distribution, and no satisfactory means are available for fully compensating for this condition. However, within the possible limits of error of the basic 26,000,000-ton estimate for San Marcial the long-term estimate for any point above San Marcial can be changed only by making compensatory changes in other estimates to allow for the excess or deficiency required to make up the load at San Marcial. The specific estimates used in this distribution are shown in Table 5.

PECOS RIVER

(1) The sediment records in the Pecos River Drainage Basin are far from satisfactory. On the main stream the 1905-07 suspended-load records (21, 22) show values obviously far below the true averages when compared with records of sediment accumulation in reservoirs. For various reasons, however, the reservoir records are subject to large corrections.

(2) Sedimentation in Alamogordo Reservoir, while accurately measured (within 5 percent), represents a period of only 6.9 years, which includes exceptional flood flows in 1937, 1941 and 1942. A substantial part of the sediment measured by the first survey in August 1940 was undoubtedly deposited during the flood of May-June 1937 but as the gates had not been installed the stored water was rapidly released, and a large amount of sediment was presumably carried out of the reservoir. Since 1937, sediment-laden density currents have carried fine material through outlets in dam during the following periods: 6/5-20/38 (heavy concentration); 9/2-9/38 (light conc.); 8/6-14/39 (medium conc.); 1940 (7 days total); 8/21-23/41 (light conc.); 9/28-29/41 (light conc. in flow over spillway); 8/16-9/11/43 (light conc.). The record, therefore, includes abnormally large sediment inflow in three years out of seven and partially compensating sediment losses from vented density currents.

Table 5. -- Estimated long-term annual sediment production and distribution in the Rio Grande Watershed above Elephant Butte Dam

Area	Drainage area	Sediment produced	Sediment deposited	Sediment production per sq. mile
	Sq. miles	Tons	Tons	Tons
Middle Valley - Cochiti to Angostura				
Rio Grande at Cochiti	1/ 11,600	9,950,000	----------	858
Rio Galisteo	2/ 697	1,250,000	----------	1,793
Sante Fe Creek	2/ 228	350,000	----------	1,535
Other Tributaries	3/ 635	750,000	----------	1,181
Deposit in Valley	------	---------	1,000,000	-----
Middle Valley - Angostura to Isleta				
Rio Grande at Angostura	1/ 13,160	11,300,000	----------	859
Rio Jemez	2/ 1,009	3,500,000	----------	3,469
Other Tributaries	3/ 833	500,000	----------	600
Deposit in Valley	------	----------	1,300,000	-----
Middle Valley - Isleta to San Acacia				
Rio Grande at Isleta	2/ 15,002	14,000,000	----------	933
Rio Puerco	4/ 6,092	17,000,000	----------	2,791
Rio Salado	2/ 1,434	5,000,000	----------	3,487
Other Tributaries	3/ 1,302	800,000	----------	614
Deposit in Valley	------	----------	5,600,000	-----
Middle Valley - San Acacia to San Marcial				
Rio Grande at San Acacia	1/ 23,830	31,200,000	----------	1,309
Other Tributaries	3/ 930	1,500,000	----------	1,613
Deposit in Valley	-----	----------	6,700,000	-----
Rio Grande at San Marcial	1/ 24,760	26,000,000	----------	1,050

1/ Drainage area given in latest U.S.G.S. Water-Supply Paper (28).
2/ Drainage area from Rio Grande Joint Investigation Report (19).
3/ Residual area obtained by subtraction.
4/ U.S.D.A. Flood Control Survey (25).

(3) The rate of silting in Lake McMillan, including above-crest deposits, is a long-term average, but does not include the large sediment losses over the spillway, which undoubtedly occurred as a result of the small capacity-watershed ratio. This ratio at present spillway level would have been originally 5.3 ac.-ft./sq. mile and was in 1940 only 2.3 ac.ft./sq.mile. Actually, before raising the spillway in 1906, the capacity-watershed ratio was 1.9 ac.ft./sq.mile, or less. Sediment losses in reservoirs having such ratios may range from 15 to 80 percent of the total incoming sediment. Probably the loss in Lake McMillan has been more than 50 percent despite the dense tamarix growth at the head of the lake which has screened out much of the fine sediment. Much sediment has also passed through Lake Avalon because the losses occurred primarily during the larger floods when both lakes were spilling rapidly. The Lake Avalon record is very low because of its even smaller capacity-watershed ratio, and the small runoff of the net drainage area between Lakes McMillan and Avalon.

(4) The Red Bluff record is undoubtedly high because it contains sediment passed through Lakes McMillan and Avalon in the 1937 flood, and later, as well as sediment from the net drainage area. The proportion of losses from Lakes McMillan and Avalon is indeterminable.

(5) In general, it is believed that rates of sediment production in the extreme upper end of the drainage basin, above Las Vegas, and along the western rim in the higher mountains (where precipitation is above 18 inches) are 100-300 T/sq.mi./yr. In the zone of 14 to 18 inches of precipitation the sediment production is higher, ranging probably from 300-2000 T./sq.mi./yr. For example Alamogordo Creek draining into Alamogordo Reservoir has contributed approximately 1700 T./sq.mi./yr., during the 6.9-year record of the reservoir survey. With still lower rainfall in the central and southern parts of the basin the sediment production is probably 200-600 T./sq.mi./yr, except in larger watersheds where stream flow originates at higher altitudes and channel erosion is severe.

APPENDIX A.

Record Number

Notes on Table 1

(1) SE 1/4 sec. 23, T.33 S., R.18 E. Sediment load (29, p. 122). Based on 36 analyses of water samples composited for 10-day or longer periods, Drainage area (28 (310)). Runoff during sampling period 8/11/11-8/14/12 (28, (310), (330)) 106% of mean annual flow for 32-year period (1905-7, 1909-21, 1924-42) (28, (930) p. 112).

(2a) Sediment load (22, p. 225). Sediment analyses (21, p. 126). Based on 39 analyses of composited water samples during period 4/10/06-3/13/07. Samples collected at Derby diversion dam. Drainage area excludes Lake Tahoe and its watershed (519 sq. miles). Runoff during sampling period at Vista, Nev., 15 miles upstream (28, (212) p. 67, (250) p. 111.).approximately 175% of estimated 90-year average for Truckee River Basin (12).

(2b) Sediment load (2, p. 309). Otherwise, see note on Record 2a.

(3) SE 1/4 sec. 33, T.19 N., R.26 E. Sediment load (2, p. 309). Sediment analyses (21, p. 24). Based on 36 analyses of composited samples during period 4/10/06-4/15/07. Runoff is for Carson River at Empire, Nev. (D. A. 988 sq. miles) (28, (212) p. 79, (250) p. 111) but flow at Hazen is approximately the same. Flow during sampling period well above normal.

(4a) Sec. 10, T.6 S., R.31 E. Sediment load (22, p. 225). Sediment analyses (21, p. 77). Based on 46 analyses of composited samples during period 5/13/06-3/30/07. Drainage area "about 450" sq. miles (28, (880) p. 82), but also reported as 400 sq. miles. Runoff during period of sampling (28 (213 p. 35, (251) p. 53) 149% of 32-year (1903-23, 1927-39) mean (28, (880) p. 82).

(4b) Sediment load (2, p. 309). Otherwise, see note on Record 4a.

(5) T.14 N., R.28 E. Unpublished data from SCS reconnaissance sedimentation survey made 9/15/39. Based on 63 sediment-thickness measurements on 7 ranges. Original capacity 13,200 A.F. Storage began 9/35. Drainage area excludes 362 sq. miles above Bridgeport Reservoir on East Walker River. Runoff estimated from reservoir outflow and allowance of 2,500 A.F. annually for evaporation. Runoff during period of measurement approximately 17% of 25-year mean annual flow estimated at 100,500 A.F. from record at Wabuska gaging station, about 20 miles upstream, and 4-year record at the dam (28, (880) pp. 147-148). A 19-year record at Schurz, Nev. (1914-18, 1920-33) (D.A. 2,850 sq. miles) was 107,000 A.F. (28, (880) p. 148). Period of sedimentation includes greatest flood flow of record on Walker River, in 1938, when 450,000 A.F. flowed through reservoir. Large amount of sediment carried past dam during this flood. Large areas of watershed practically never contribute direct surface runoff or sediment.

(6) Sec. 24, T.39 N., R.62 E. Unpublished data from SCS reconnaissance sedimentation survey made 9/39. 46 sediment measurements on 8 ranges. Original capacity approximately 30,000 A.F. Effective sediment-contributing area less than half of natural drainage area of approximately 57 sq. miles because of depression above the lake in which sediment from headwaters is deposited. No runoff records, but Truckee River runoff during this period 88% of 90-year mean (12).

(7) Sec. 27, T.39 N., R.48 E. Unpublished data from SCS reconnaissance sedimentation survey made 9/39. 62 sediment measurements on 6 ranges. Drainage area determined by planimeter from new maps on scale of 1 in.=2 mi. Original capacity 15,300 A.F. No runoff records, but Truckee River runoff during period 79% of 90-year mean (12).

(8) T.30-31 N., R.32-33 E. Unpublished data from SCS reconnaissance sedimentation survey made 9/39. 73 sediment measurements on 13 ranges. Maximum permitted storage in 1939 was 80,000 A.F. Designed storage capacity 179,000 A.F. Storage began 3/15/35. Runoff during period of sedimentation 48% of 27-year (1899-1909, 1910-16, 1917-22, 1930-32, 1935-39) mean annual flow of 147,400 A.F. (28, (790), (810), (830), (860), (880)). Due to large irrigation diversions and reservoir storage upstream, flow has decreased in later years, and only a small part of 13,700 sq. miles actually contributes sediment this far downstream.

(9) T.5 N., R.11 W. Data from SCS detailed sedimentation surveys on 10-ft. C.I. (4). Original capacity 4,217 A.F. at elev. 3250. Approximately half of sediment deposited in storm of 3/2/28. Data do not include 209 A.F. of above-crest deposits measured after 1938 storm. Maintenance of high rate due largely to these deposits being carried down into reservoir. Average runoff 9 years (1930-38, 1939-41) 15,000 A.F., but this does not include 1938 flood when most of sedimentation occurred.

(10) Sec. 11, T.8 N., R.15 W. Unpublished data from SCS reconnaissance sedimentation survey made 6/30/39. 38 sediment measurements on 5 ranges. Original capacity 7,487 A.F. Drainage area excludes reservoir surface, 172 acres. Reservoir fed through Los Angeles Aqueduct from Owens Valley. Part of sediment probably comes from this sources.

(11) Dam at NW 1/4 sec. 1, T.17 S., R.2 W. Data obtained from Utah State Engineer. Based on 5-foot C.I. survey in 1908, and 1-foot C.I. resurvey 1932. Storage began about 1904. Capacity 1908 at present spillway elevation was 250,000 A.F. Drainage area net below Rocky Ford and Gunnison Reservoirs. Sediment during earlier part of period from entire drainage area of 5120 sq. miles. Considerable quantities of sediment now pass through Rocky Ford Reservoir. Runoff is from station below San Pitch River (1917-32, D.A. 4,880 sq. miles); station near Gunnison (1909-16, D.A. 3,990 sq. miles); station on San Pitch River (1913-15, 1917, D.A. 886

sq. miles); plus estimate of 25,000 A.F. annually for San Pitch River (1909-12, 1916), (28, (880) pp. 141-143). Large diversions above station.

(12) T.22 S., R.1 & 2 W. Unpublished data from SCS reconnaissance sedimentation survey made 11/40. 36 sediment measurements made on grid spacing. Original capacity 2,115 A.F. Indicated low sediment production due to low ratio of capacity to drainage area. Large proportion of sediment passes through reservoir. Runoff is mean annual for 27 years (1914-41) (28, (930) p. 71). Large diversions above station. Gross D.A. 3,340 square miles.

(13) Dam at NW 1/4 sec. 3, T.29 S., R.3 W. Data based on contour surveys made in 1908 by State Engineer, and 1938 by J. L. Ogden and W. C. Cole. Original capacity 81,200 A.F. at elev. 76. Drainage area net below principal upstream reservoirs. Gross drainage area 2,440 sq. miles. Mean annual outflow from reservoir 29 years (1912-41) 181,400 A.F. (28 (930) p. 69). Allowing 5,000 A.F. for annual net evaporation, estimated annual inflow 186,400 A.F.

(14) Dam at NE 1/4 sec. 11, T.30 S., R.9 W. Unpublished data from SCS reconnaissance sedimentation survey made 11/40. 45 sediment measurements on 7 ranges. Original capacity 23,260 A.F. at elev. 51.0. Runoff estimated from outflow 26 years (1914-36, 1937-41), 28,100 A.F. (28, (930) p. 80), plus allowance 2,500 A.F. annual net evaporation.

(15) Sec. 25 & 36, T.27 S., R.6 W. Unpublished data from SCS reconnaissance sedimentation survey made 11/5/40. 14 sediment measurements on 3 ranges. Original capacity 318 A.F. to spillway elevation established 1937. No runoff records. Low sedimentation rate due to low capacity-watershed ratio and well vegetated drainage area.

(16) Sec. 33 & 34, T.37 S., R.18 W. Unpublished data from SCS reconnaissance sedimentation survey made 11/14/40. 67 sediment measurements on grid spacing. Original capacity approximately 9,000 A.F. No runoff records.

(17) Sec. 20, T.35 S., R.8 W. Unpublished data from SCS reconnaissance sedimentation survey made 11/13/40. Storage began 12/26. 23 sediment measurements on grid spacing. Original capacity approximately 600 A.F. No runoff records.

(18) Sec. 22, T.18 N., R. 107 W. Sediment load (22, p. 224). Sediment analyses (21, p. 46). Based on 22 analyses of composited samples during period 5/1-11/1/05. Flow during period (28, (469) p. 257) 59% of mean annual flow 34 years (1895-99, 1900-06, 1915-39) of 1,352,900 A.F. (28, (879) p. 92).

(19) NW 1/4 SW 1/4 sec. 15, T.21 S., R.16E. Sediment load (10, p. 17). Based on sampling "every few days" 8/1/14-7/30/15. Flow during period (28, (389) p. 19, (409) p. 22.) 74% of mean annual flow 41 years (1894-99, 1905-41), (28, (929) p. 112).

(19b) NW 1/4 Sw 1/4 sec. 15, T.21 S., R.16 E. Sediment Load (27). Based on almost daily sampling. Flow during sampling period (27) 70% of 41-year average (1894-99, 1905-41), (28, (929) p. 112).

(20) Sec. 23, T.1 N., R.81 W. Sediment load (22, p. 224). Sediment analyses (21, p. 42). Based on 20 analyses of composited samples 4/23-10/16/05. Flow during sampling period (28, (175) p. 81) 71% of 14-year average, (1905-18), (28, (879) p. 264).

(21) Sec. 2, T.11 S., R.98 W. Sediment load (22, p. 224). Sediment analyses (21, p. 45). Based on 28 analyses of composited samples 3/15/05-5/5/06. Flow during sampling period (28, (175) p. 86, (211) p. 75) 102% of 32-year average (1902-33), (28, (879) p. 265).

(22a) NW 1/4 sec. 17, T.23 S., R.24E. Sediment load (10, p. 17). Based on sampling "every few days" 11/10/14-7/31/15. Flow during sampling period (28, (409) p. 69) 77% of 23-year average (1914-17, 1922-41), (28, (929) p. 18).

(22b) NW 1/4 sec. 17, T.23 S., R.24E. Sediment load (27). Based on almost daily sampling. Flow during sampling period (27) 83% of 23-year average (1914-17, 1922-41), (28, (929) p. 18).

(23) T.12 S., R.99 W. Sediment load (22, p. 224). Sediment analyses (21, p. 50). Based on 31 analyses of composited samples 4/2-10/31/05. Flow during sampling period (28, (175) p. 115) 108% of 21-year average at Grand Junction, Colo., (1917-30, 1933-41) (D.A. 8,020 sq. miles), (28, (929) p. 78).

(24a) NE 1/4 SE 1/4 sec. 13, T.40 N., R.7 E. Sediment load (27). Based on almost daily sampling. Flow during sampling period (27) 102% of 20-year average (1921-41), (28, (929) p. 19).

(24b) Sediment load and runoff obtained by subtracting mean runoff and suspended load for period 10/1/29-9/30/33 included in Records 19b, 22b, and 25b, from corresponding data for same period in Record 24a.

(25a) SW 1/4 sec. 7, T.42 S., R.19 E. Sediment load (10, p. 17). Based on sampling "every few days" 11/1/14-8/31/15. Flow during sampling period (28, (409) p. 118) 125% of 16-year average (1915-17, 1927-41), (28, (929) p. 177).

(25b) SW 1/4 sec. 7, T.42 S., R.19 E. Sediment load (27). Based on almost daily sampling. Flow during sampling period (27) 89% of 16-year average (1915-17, 1927-41), (28, (929) p. 177).

(26) Sec. 20, T.35 N., R.9 W. Sediment load (22, p. 224). Sediment analyses (21, p. 14). Based on 30 analyses of composited samples 3/19-12/18/05. Flow during sampling period 139% of 40-year average (1895-1900, 1901-05, 1910-41), (28, (929) p. 195).

(27) Data from (13). Sediment load computed from samples collected every few minutes during storm runoff on ephemeral streams. Long-term average runoff estimated at 400 A.F. based on comparison with Sante Fe precipitation index.

(28) See Footnote 27. One flood in 1941 not sampled, but total runoff and peak flow in this year well above normal average. Long-term average runoff estimated at 200 A.F.

(29) See Footnote 27. Long-term average runoff estimated at 100 A.F.

(30) Sec. 7, T.16 N., R.22 E. Sediment load (22, p. 224). Sediment analyses (21, p. 56). Based on 27 analyses of composited samples 8/6/05-4/3/06. Flow during sampling period (28, (175) p. 148, (211), p. 107) 168% of 10-year average (1905-08, 1915-19, 1929-33, 1935-41, incomplete). (28, (929) p. 217).

(31) Sec. 18, T.10 N., R.18 W. Data from (7, pp. 18-19). Original source U. S. Indian Service records. Sediment accumulation based on comparative contour surveys to elevation 1000, local datum. Original capacity at this elevation 15,811 A.F. Estimated average sediment loss of 50 A.F. annually in irrigation water released and 100 A.F. in spillway overflows; 28% of total sediment has passed through reservoir. Effective sediment-contributing drainage area probably not more than 500 sq. miles.

(32a) Lat. 36°05'55", long. 112°05'30". Sediment load and runoff (27). Based on almost daily sampling. Discharge measured only 2 years longer than suspended load.

(32b) Sediment load and runoff obtained by subtracting data for period 10/1/29-9/30/33 in Record 24a from data for corresponding years in Record 32a.

(32c) Sediment load and runoff obtained by subtracting data for period 10/1/29-9/30/41 in Records 19b, 22b, and 25b from data for corresponding years in Record 32a.

(33) SE 1/4 SE 1/4 sec. 22, T.41S., R.12 W. Data from U. S. Bureau of Reclamation. Letter from J. C. Page, Commissioner, to H. H. Bennett, Chief, Soil Conservation Service, dated 1/22/43. Based on 187 samples in 1936 and 136 samples in 1941. Flow 114% of 22-year average annual (1910-14, 1915-16, 1917-18, 1923-24, 1926-41), (28, (929) p. 226).

(33-1) NE 1/4 sec. 36, T.11N., R.17 W., site of U.S.G.S. stream gaging station near Planet, Ariz. from which runoff data are obtained. Sediment data based on SCS reconnaissance sedimentation survey in May 1941 of Williams arm of Lake Havasu created by Parker Dam, and area of main lake extending to 3000 feet above Williams River mouth. Total drainage area of Williams River estimated 5300-5500 sq. mi. Water impounded in Lake Havasu 10/16/38. Runoff during period 196% of 14-yr. average (1928-42) of 124,300 A.F.

(34) Sediment load (22, p. 224). Sediment analyses (21, p. 119). Based on 30 analyses of composited samples 4/14/05-4/22/06. Flow during sampling period (28, (175) p. 170, (211) p. 128) 269% of 12-year mean flow (1928-31, 1932-41) at Glenwood, a few miles downstream. (28, (929) p. 262). Drainage area is that at Glenwood (NE 1/4 NW 1/4 sec. 23, T.12S., R.20 W).

(35) NW 1/4 sec. 17, T.6 S., R.25 E. Unpublished data (26), based on SCS sedimentation surveys on 5 ft. C.I. of 11.43-A.F. stock tank No. 16 (Bryce Dam). Long-term mean sediment load estimated at 80% of that recorded based on rainfall analysis.

(36) Unpublished data (26) based on SCS reconnaissance sedimentation range survey. Sediment 18% sand and coarser, 82% silt and finer. Long-term sediment load estimated at 80% of that recorded based on rainfall analysis.

(37) Unpublished data (26) based on SCS reconnaissance sedimentation range survey. Sediment 50% sand and coarser, 50% silt and finer. Long-term sediment load estimated at 80% of that recorded based on rainfall analysis.

(38) Unpublished data (26) based on SCS reconnaissance sedimentation range survey. Sediment 17% sand and coarser, 83% silt and finer. Long-term sediment load estimated at 80% of that recorded based on rainfall analysis.

(39) Unpublished data (26) based on SCS sedimentation range surveys of silt barrier, 9 miles North of Duncan, Ariz. Original capacity 33.3 A.F. Constructed 7/37. Deposited material all sand size or coarser. Estimated at least 20% of total material passed dam, but long-term sediment load estimated at 80% of that recorded.

(40a) Sec. 17, T.3 S., R.18 E. Sediment load and runoff (10, p. 20). Based on 30 analyses of composited samples 6/1-12/30/05. Flow during period 63% of average annual flow of 403,000 A.F. for 74-year period (June 1867-June 1941) estimated by U. S. Army Engineers in unpublished flood control report on Gila River drainage basin. Average flow during 46 years of measurement given by same source as 381,000 A.F. Drainage area excludes interior drainage around Lordsburg and elsewhere.

(40b) Dam at NW 1/4 sec.17, T.3S., R.18 E. Sediment accumulation (7, pp. 99-110) based on detailed contour surveys but subject to small error due to inaccuracy of original reservoir maps. Storage began 11/15/28. Survey made 3/1/35. Incomplete survey 1/37 showed approximately 40,000 A.F. sediment. Inflow during period of sedimentation to 1935, 1,738,106 A.F. (as compiled by Indian Service) was, on annual basis plus allowance of 2000 A.F. annually for unmeasured inflow, 77% of 46-year mean flow (1895-1940) and 68% of mean inflow for 74-year period as estimated by U. S. Army Engineers. Watershed area excludes interior drainage.

(41a) Sec. 20, T.4 N., R.12 E. Sediment load (22 p. 224). Sediment analyses (21, p. 113). Based on 27 analyses of composited samples 4/9/05-4/23/06. Flow during sampling period (28, (175) p. 177, (211) p. 133) 298% of flow during 30-year period (1909-39). Sediment production per square mile almost twice as great as shown in Record 41b, but probably much below actual amount for this year of exceptional runoff.

(41b) Sec. 20, T.4 N., R.12 E. Unpublished data from files of Salt River Valley Water Users Association, Phoenix Ariz. Based on contour and range surveys by Association. Original storage capacity at present spillway elevation 234, (local datum) 1,522,200 A.F. Reservoir completed February 1911, but storage began in 1909. Runoff for first several years partially estimated.

(42a) 3/4 mile above mouth of Verde River. Sediment load (22, p. 224). Sediment analyses (21, p. 132). Based on 23 analyses of composited samples 4/5/05-3/10/06. Flow during period (28, (175) p. 181, (211) p. 139) 144% of average annual flow during 38-year period (1895-1898, 1901, 1904-38), (28, (879) p. 302).

(42b) Sec. 34, T.6 N., R.7 E. Unpublished data from SCS reconnaissance sedimentation survey made 2/1/41. 56 sediment measurements on 10 ranges. Original storage capacity 182,608 A.F. Storage began 2/5/39. Large amount of sediment discharged through sluice gates. estimated for certain periods at 50% of total sediment inflow. Flow during period (28, (879), (899), (929)) 75% of 16-year average (1925-41) on Verde River above Bartlett Reservoir (D. A. 6,040 sq. miles), (28, (929) p. 292).

(43) Dam at NW 1/4 sec. 21, T.6 N., R.1 E. Unpublished data from SCS reconnaissance sedimentation survey made 2/23/41. 79 sediment measurements on 8 ranges. Original storage capacity 184,500 A.F. plus small dead storage. Dam closed 2/1/28 but 45,260 A.F. of water had then accumulated. Sediment depth up to 57 feet near dam. Runoff during period 39% of 29-year average (1911-40), according to records supplied by Maricopa County Municipal Water Conservation District No. 1, Phoenix, Ariz.

(44) Sec. 7, T.20 N., R.10 E. Unpublished data from SCS reconnaissance sedimentation survey made 4/41/ Based on sediment depth measurements and sounding profiles plotted over profiles drawn from original topographic maps along ranges. Original storage computed from original maps approximately 4,048 A.F. Runoff during period (28, (878) p. 380, (898) p. 258, (928), p. 234) 98% of 25-year average (1916-29, 1930-42) at Cundiyo (D.A. 86 sq. miles), (28, (958) p. 233).

(45) T.23 N., R.7 E. Unpublished data (25, 28a). Record covers period 1937-41, except 12/38, 1-2/39, 12/39, 1-2/40, 1/41 and 10-12/41.

Flow and sediment load during these months, based on records of other years, was negligible. Number of samples taken unknown. Runoff estimated in part from gaging station near El Rito (28).

(46) T.22 N., R.8 E. Unpublished data (25, 28a). Record used here covers period 1937-38, except 1-2/37 and 5/38 which are estimated. Records are available through 9/42 except for months of highest flow and largest sediment load. Number of samples taken unknown. Flow for missing months in 1937 and 1938 taken as that at Rio Ojo Caliente gaging station at La Madera, N. Mex. Sediment load for missing months estimated from comparison with months of similar discharge to complete 2-year record. Results only approximate. Runoff during 2-year period 141% of 10-year average (1932-42), (28 (958) p. 232).

(47) Sec. 8, T.21 N., R.8 E. Unpublished data (25,28a). Record covers period 1/37 through 9/43, except 6/39, 7/40 and 8/41. Months in 1943 excluded, and full 6-year record calculated here. Records also available for 2 upstream points with gaps for several months. Approximately 113 samples taken to 3/39. Runoff during period 112% of 28-year (1913-17, 1918-42) average flow of 521,067 A.F. (28, (958) p. 229).

(47-1) T.21 N., R.8 E. Unpublished data (25, 28a). Record covers period 1/37 through 9/43. Months in 1943 excluded and full 6-year record calculated here. Number of samples unknown. Discharge probably estimated from upstream Embudo Station with allowance for losses and gains.

(47-2) T.20 N., R.8 E. Unpublished data (25, 28a). Record covers years 1937 through 1942. Number of samples unknown. Discharge probably estimated from upstream and downstream stations.

(48) T15 N., R.6 E. Unpublished data (25, 28a). Record covers period 4/37 through 4/40, except 1/38 and 11-12/39, which are believed to have had negligible flow. Incomplete records for additional months through 8/42. Based on approximately 131 samples through 6/39. Long-term average flow unknown.

(49) Sec. 32, T.16 N., R.2 E. Unpublished data (25,28a). Record covers period 11/36 through 9/41. October flow and load commonly negligible. Number of samples unknown. Record of flow at this station only slightly longer than sediment record.

(50) T.15 N., R.2 E. Unpublished data (25, 28a). Record covers period 11/36 through 9/41. October flow and load commonly negligible. Based on approximately 219 samples through 8/40. Runoff estimated.

(51) T.15 N., R.1 E. Unpublished data (25, 28a). Record covers period 2/37 through 9/40, and 2/41 through 6/41. Months in 1941 omitted. Estimates of flow and sediment for 1/37 and 10-12/40 made to give full 4-year period. Number of samples unknown. Runoff estimated.

(52) Sec. 6, T.8 N., R.3 W. Unpublished data (25, 28a). Record covers period 1937 through 1941, except 11-12/41. Commonly no flow during November and December. Number of samples unknown. Runoff estimated.

(52-1) Exact location undetermined. Unpublished data (25, 28a). Record covers period 3/37 through 9/41. Months in 1941 omitted and discharge and sediment for 1-2/37 estimated to give full 4-year record. Number of samples unknown. Runoff estimated.

(53) Exact location undetermined. Unpublished data (25, 28a). Drainage area is approximate, being above a point near Suwanee, N. Mex. Record covers period 1937 through 1941, except 11-12/41. Commonly no flow during November and December. Number of samples unknown. Runoff estimated.

(54) Sec. 4, T.9 N., R.1 W. Unpublished data (25, 28a). Record covers period 1937 through 1941, except 11-12/41. During November and December flow and sediment load is commonly negligible. Number of samples unknown. Runoff estimated.

(55) W 1/2 sec. 31, T.7 N., R.1 W. Unpublished data (25, 28a). Record covers period 11/36 through 9/42, except 10/40, 10/41, 4-5/42 and 9/42. Months in 1936 and 1942 omitted and sediment load for 10/40 and 10/41 estimated from loads measured at upstream and downstream stations. Based on 231 samples through 9/40. Runoff during 5-year period 92% of 17-year runoff (1913-17, 1919-20, 1921-24, 1926-27, 1934-42) of 78,774 A.F., (28, (958) p. 237). Drainage area as given by U.S.G.S., but also reported as 4,795, sq. miles (19).

(56) Lat. 34°24'30", long. 106°51'10". Unpublished data (25, 28a). Record covers period 2/37 through 12/41. Flow and sediment for 1/37 estimated. Based on 282 samples through 9/40. Drainage area uncertain; area used from (25). Area of 5402 sq. miles could be obtained by adding 242 sq. miles reported (19) as uncontrolled drainage below Rio Puerco to U.S.G.S. figure for that station (28, (928) p. 251). Total drainage area also given as 5,073 sq. miles (19). Probable average annual discharge 62,400 A.F. (25).

(57) Sec. 31, T.1 N., R.1 W. Unpublished data (25, 28a). Record covers period 1937 through 1941, except 1-2/37, 5-6/40, 10-12/40, 1-3/41 and 11-12/41. Flow and sediment load in January through April and November-December, ordinarily negligible. Missing load for other months in 1940-41 considered not appreciable. Based on approximately 120 samples through 12/39. Flow estimated. Drainage area (19, p. 174).

(58) Sec. 23-26, T.10 N., R.5 W. Data supplied by Office of Indian Affairs, U. S. Department of the Interior. Based on topographic surveys of 2' C.I. made 2/1/38 and 8/1/40. Storage began winter of 1938. Original capacity approximately 990 A.F. Low capacity-watershed ratio.

(59) T.16 N., R.6 E. Unpublished data (25, 28a). Record covers period 11/36 through 9/43. Sediment for 10/36 assumed as 0.1 percent of flow based on comparisons of other months. Based on 1928 samples during 47 months averaging approximately one sample per day. Probably 5% of total sediment diverted into canals above sampling station. Runoff (28, (878), (898), (928), 28a) during 4-year period 122% of 16-year average (1925-41) of 1,126,000 A.F. (28, (928, p. 169).

(60) Sec. 1, T.14 N., R.4 E. Unpublished data (25, 28a). Record covers period 10/36 through 9/43, except 10/36, 11-12/42, 1/42. Sediment estimated for these months based on comparison with months of similar flow. Based on 1,198 samples through 9/40. Runoff (28, (878), (898), (928), 28a) obtained from San Felipe station 4 miles upstream. (D.A., net, 13,160 sq. miles). No diversion and negligible inflow between stations. Runoff during sampling period 113% of 15-year average (1926-41) of 1,214,000 A.F. (16, (928) p. 170).

(61) Sec. 1, T.2 N., R.1 E. Unpublished data (25, 28a). Record covers period 11/36 through 2/42. Months in 1936 and 1942 omitted to give full 6 year period. Based on 44 samples to 9/40. Discharge 10/36 through 12/38 (28, (828), (858), (978)); 1/39 through 2/43 estimated by observer at time of sampling and checked with upstream and downstream records, diversions, etc.

(62) Sec. 1, T.1 S., R.1 W. Unpublished data (25, 28a). Record covers period 11/36 through 9/43. Sediment for 10/36 estimated based on comparison with months of similar flow. Based on 1,594 samples to 9/40. Runoff (28, (828), (858), (878), (898), (928), 28a).

(63) T.7 S., R.1 W. Sediment records compiled by SCS Sedimentation Section as follows: For 1897-1912 (9). For part of 1905 and succeeding years based on periodic sampling. The earlier part of the record was estimated from sampling records at El Paso and San Marcial in the later years. Data for years 1913-24 (22, pp. 207, 250). Based on sampling during 1919 and for other years on "silt rating curves" prepared in 1924, by T. R. Neiswander of Rio Grande Project, U.S. Bureau of Reclamation, from earlier records. Data for years 1925-41 (14, (2-11)). Frequency of sampling quite variable. For number of samples and methods used, see reports cited. Discharge as compiled slightly different from reported 45-year average (1896-1941) of 1,121,630 A.F. (28, (928), P. 172).

(64) Dam at NW 1/4 sec. 30, T.13 S., R.3 W. Sediment data from (7, p. 99) and other sources. Annual sediment load is sum of deposits in active storage area of reservoir (elevations 4231.5 to 4407) as determined by 1935 survey, 365,186 A.F.; plus 3,432 A.F. in dead storage below elevation 4231.5; plus estimated 5,000 A.F. vented from reservoir (8); plus 13,929 A.F. of deposits above elevation 4,407 and below the San Marcial gaging and sampling station as determined by SCS surveys. Specific weight estimated. Follett (9) used 53 lbs./cu.ft. International Boundary Commission (14, (7) p. 63) calculated 70.2 lbs/cu.ft. from comparison of suspended load and reservoir records. Runoff during sedimentation period (28, (878) p. 113) 96% of 45-year average (1896-1941), (28, (928) p. 172).

(65) Sediment data are reported (14, (2) p. 51) as only roughly approximate because of the infrequency of sampling (213 samples in 9 years, less than 10 in some years). Drainage area is net below Elephant Butte Reservoir. Much of sediment is from channel scour below Elephant Butte Dam. Much sediment also diverted in irrigation water. Flow during sampling period (14, (2) p. 51) 85% of 53-year average flow (1889-1941) (14) but part of long-term period was before regulation by Elephant Butte Reservoir and extensive irrigation diversions.

(66) Sediment data are reported (14, (2) p. 52) as only roughly approximate because of infrequency of sampling (207 samples during period). Drainage area is net below Elephant Butte Reservoir. A large amount of sediment is diverted with water out of channel before reaching this station. Flow during sampling period 97% of 19-year average flow (1923-41) (14).

(67) Sediment load (22, p. 228). Sediment analyses (14, (1) p. 36). Based on 26 samples per year for period. Results very approximate. Drainage area net below Elephant Butte Reservoir. Runoff during sampling period 208% of average during 18-year period (1924-41) (14, (11) p. 17).

(68) Sediment load (22, p. 228). Sediment analyses (14, (1) p. 37). Based on 26 samples per year for period. Results very approximate. Drainage area net below Elephant Butte Reservoir. Runoff during sampling period 216% of average during 18-year period (1924-41), (14 (11) p. 19).

(69) Sec. 27, 28, 33 34 T.17 N., R.16 E. Sediment data (20, p. 142). Based on SCS reconnaissance sedimentation survey made 8/29/40. 53 sediment measurements on 4 ranges. Original capacity approximately 23,000 A.F. Off-channel. Receives water by diversion from 90 sq. miles of Gallinas River watershed, and directly from 45 sq. miles of Sanguijuela and 15 sq. miles of Arroyo Pecos. No inflow data.

(70) Lat. 35°39'15", long. 105°16'30". Sediment load (22, p. 228). Sediment analyses (21, p. 39). Based on 42 analyses of composited samples during period 3/19/05-3/31/06. Flow during sampling period (28, (174) p. 117, (210), p. 98) 176% of 34-year average flow (1905-11, 1913-41). (28, (928), p. 284).

(71) Sec. 12, T.10 S., R.12 E. Sediment data (20, p. 142). Based on SCS reconnaissance sedimentation survey made 8/27/40. 28 measurements on 6 ranges. Original capacity 1,180 A.F. No runoff data.

(72) T.11 S., R.22 E. Sediment load and runoff (22, p. 228). Sediment analyses (21, p. 52). Based on 16 analyses of composited samples during period 3/26-8/4/05.

(73) Sec. 2, T.8 N., R.21 E. Sediment load (22, p. 228). Sediment analyses (21, p. 88). Based on 65 analyses of composited samples

during period 7/7/05-12/29/06. Flow during sampling period (20, p. 187) 141% of 35-year (1905-39) average flow of 113,000 A.F. (20, p. 187).

(74) T.5 N., R.24 E. Sediment data computed by SCS. Based on SCS detailed sedimentation range survey of 8/1/40 and resurvey of these ranges by U. S. Engineer Office, Albuquerque, N. M. in April 1944. Original total capacity determined by 1940 survey 154,751 A.F., compared with 156,750 A.F. total storage determined from original contour maps by U. S. Bureau of Reclamation. Storage as of April 1944 above elevation 4200 determined by U. S. Engineer Office based on contour method was 132,171 A.F. Storage remaining below elevation 4200 small. Total storage as of April 1944 determined by SCS based on range method 130,339 A.F. Sediment volume obtained by subtracting U. S. Engineer Office figure from U.S.B.R. original capacity is 24,579-A.F. Sediment volume determined by SCS was 24,412 A.F. below spillway level and 597 A.F. above-crest within original flow line. Differences are within limits of error of surveys. Contributing drainage area used here determined by U. S. Engineer Office. Topographic watershed area is 4,393 sq. mi. Beginning of storage taken as 5/27/37 when water began to rise from elevation 4160 and reached 4260.9 on 6/3/37. Estimated maximum discharge of flood 75,000 c.f.s., and maximum total storage obtained 99,800 A.F. Completely drained 7/9/37. Outlet tunnel gates not installed and continuous discharge during flood was 800-4,800 c.f.s. Temporary gates installed 9/1/37. Significant sediment deposition reported during May-June, 1937, flood. Total inflow during period 5/27/37-4/1/44 estimated at 1,917,000 A.F. based on discharge records at U.S.G.S. gaging station, Guadelupe, N. Mex. just below dam in 1937-1938, (D.A. 4,393 sq. miles) (28, (828) p. 402, (858), p. 323), plus storage in reservoir on 1/1/39 (28, (878), p. 288) (evaporation and seepage losses disregarded); and at Puerto de Luna station just above reservoir after 1/1/39 (28, (878), p. 287; (898), p. 311, U.S.G.S. and U.S.B.R. preliminary estimates) plus allowance of 25,000 A.F. unmeasured inflow from Alamogordo Creek. Flow during period of record was 144% of 39-year mean flow (1905-43). In addition to deposits it is estimated from U. S. G. S. water sampling records that 100 T./sq.mi./yr. have passed through outlets and over spillway. Long-term sediment production estimate based on 39-year mean flow and sediment concentration in runoff plus sediment losses past dam and unmeasured deposits above flow line.

(75) Sec. 18, T.17 S., R.27 E. Sediment load (22, p. 228). Sediment analyses (21, p. 87). Based on 67 analyses of composited samples during period 7/20/05-4/20/07. Record covers most of two runoff years. Annual flow (20, p. 192) was 141% of 35-year average discharge, (20, p. 192).

(76) Sec. 2-3, T.20 S., R.26 E. Sediment data (20, p. 141), and correspondence with L. E. Foster, Supt., Carlsbad Project, U.S.B.R. Data based on U.S.B.R. survey, average date 1/1/40. Original capacity as of 1/1/94, at present spillway elevation 3267.7, given as 90,000 A.F., but reservoir basin was not mapped to this elevation at that date, and capacity curve extension suggests this figure may be too low. Capacity 1940, 38,655 A.F. In addition, above elevation 3267.7 and below Dayton Highway 21,880 A.F. was deposited 1915-40 as above-crest deposits due to reservoir. Estimated 4,000 A.F. additional deposit from Dayton Highway to Dayton gaging station 1-1/4 mile upstream. Minimum total deposit is thus 77,225 A.F. Estimated sediment loss over spillway at least 25% of sediment inflow. Flow is 35-year mean (1905-39) at Artesia (Dayton), (20, p. 192).

(77) T.22 S., R.27 E. Sediment data (20, p. 142). Based on SCS reconnaissance sedimentation survey made 4/25/40. 13 sediment measurements on 3 ranges plus measurements on exposed delta. Original capacity about 7,600 A.F. This record is of little value because much of sediment has come through Lake McMillan, and probably much over half of sediment entering Lake Avalon has passed downstream. Drainage area net below Lake McMillan.

(78) Just south of New Mexico-Texas state line. Sediment data (20, p. 142). Based on SCS reconnaissance sedimentation survey of 7/16-17 and 8/25-26/40. 60 sediment measurements on 8 ranges. Original capacity 310,000 A.F. Storage began June 1937. Runoff (28, (828), (858), (878), (898)) from combined stations at Red Bluff and on Delaware River after 10/1/37, and at Angeles station prior to that date. Annual runoff during period 84% of 35-year mean (20, p. 195), but heavy flood of June 1937, in which month total runoff was 421,400 A.F., caused abnormal sedimentation. Record considered too high for average. Sediment comes partly from upper watershed through Lakes Avalon and McMillan and partly from net drainage area.

(79) Sediment data (20, p. 142). Based on SCS reconnaissance sedimentation survey made 8/23/40. 14 sediment measurements on 4 ranges. Original capacity 313 A.F. No runoff records.

(80) Sediment data (20, p. 142). Based on SCS reconnaissance sedimentation survey made 8/22/40. 36 sediment measurements on 4 ranges. Original capacity 6,155 A.F. Fed by diversion from Toyah Creek. Not all of sediment from drainage area goes into reservoir, but part of deposits have come from scouring of diversion channel between Toyah Creek and reservoir. No runoff records.

Literature Cited

(1) Anonymous.
More Water and Power, Less Silt for the San Carlos Project, Main Buttes Dam Objective. Ariz. Prod. 17 (13): 23. Sept. 15, 1938.

(1a) Benedict, P. C.
Preliminary Field Tests of the U.S. Sediment-Sampling Equipment in the Colorado River Basin. U.S. Geol. Survey 10 pp., illus. April 1944. [Processed]

(2) Bonner, Frank E.
Discussion of "Modifying the Physiographical Balance by Conservation Measures," by A. L. Sonderegger. Amer. Soc. Civ. Engin. Trans. 100: 307-315. 1935.

(3) Branch, L. V.
Aqueduct Operating Program Engin. News-Rec. 121 (21): 678 Nov. 24, 1938.

(4) Brown, Carl B.
Report on the Sedimentation Surveys of Little Rock Reservoir, Los Angeles County, California. U.S. Soil Conserv. Serv. Spec. Rpt. 6. 11 pp., illus. 1943.

(5) Brown, Carl B.
Discussion of "Sedimentation in reservoirs" by B. J. Witzig. Amer. Soc. Civ. Engin. Proc. 69 (9): 1493-1499, illus. Nov. 1943.

(6) Debler, E. B.
Stream flow of Lower Colorado River and its Tributaries. U.S. Bur. Reclam., 134 pp., illus. Dec. 1934. [Processed]

(7) Eakin, H. M. and Brown, Carl B.
Silting of reservoirs. U.S. Dept. Agr. Tech. Bul. 524, 168 pp., illus. Revised August 1939.

(8) Fiock, L. R.
Records of Silt Carried by the Rio Grande and its Accumulation in Elephant Butte Reservoir. Amer. Geophys. Union Trans. 15 (2): 468-473. 1934.

(9) Follett, W. W.
Silt in the Rio Grande. (U.S. Dept. of State, Internatl. Boundary Comn. and Comn. for the Equitable Distribution of the Waters of the Rio Grande, United States and Mexico.) 102 pp. [Washington, D. C. 1913]

(10) Fortier, S., and Blaney, H. F.
Silt in the Colorado River and its Relation to Irrigation. U.S. Dept. Agr. Tech. Bul. 67, 95 pp., illus. 1928.

(11) Harding, S. T. Changes in Lake Levels in Great Basin Area. Civ. Engin. 5: 87-90, illus. Feb. 1935.

(12) Hardman, George, and Cruz, Venstrom.
A 100-Year Record of Truckee River Runoff Estimated from Changes in Levels and Volumes of Pyramid and Winnemucca Lakes. Amer. Geophys. Union Trans. 22 (1): 71-90, illus. 1941.

(13) Harrold, L. L.
Thunder-storms and Runoff at High Elevations in Northwestern New Mexico. Amer. Geophys. Union Trans. 24 (2): 425-437, illus. 1943.

(13a) Happ, S. C.
Sedimentation in the Middle Rio Grande Valley, New Mexico. U.S. Dept. Agr. Soil Conservation Service. /Unpublished/ 1943.

(14) International Boundary Commission.
Flow of the Rio Grande and Tributary Contributions. Water Bulletins Nos. 1-11, 1930-41.

(15) Johnson, J. W.
The Use of Mass-Curves in Evaluating Suspended-load Observations on Small Piedmont Streams. Amer. Geophys. Union Trans. 23 (2): 664-672, illus. 1942.

(16) Lane, E. W., and Koelzer, V. A.
Density of Sediments Deposited in Reservoirs. Report No. 9 in A Study of Methods used in Measurement and Analysis of Sediment Loads in Streams. 60 pp., illus. Iowa City. November 1943.

(17) La Rue, E. C.
Colorado River and its Utilization. U.S. Geol. Survey Water-Supply Paper 395, 231 pp., illus. 1916.

(18) Love, S. K.
Suspended Matter in Small Streams. Amer. Geophys. Union Trans. 17 (2): 447-452, illus. 1936.

(19) National Resources Committee.
Regional Planning, Part VI - The Rio Grande Joint Investigation 1936-1937. Vol. 1, 566 pp., illus. 1938.

(20) National Resources Planning Board.
Regional Planning, Part X - The Pecos River Joint Investigation. 207 pp., illus. 1942.

(21) Stabler, Herman.
Some Stream Waters of the Western United States. U.S. Geol. Survey Water-Supply Paper 274, 188 pp., illus. 1911.

(22) Stevens, J. C.
The Silt Problem. Amer. Soc. Civ. Engin. Trans. 101: 207-288, illus. 1936.

(23) Tipton, R. J.
Report on Water Supply of Colorado River and Allied Matters. Exhib. C of the Rpt. and Proc. of the Fact Finding Committee of the Upper Colorado River Basin States. July 1938.

(24) United States Bureau of Reclamation.
Lake Mead Density Currents Investigations, 1937-1940. Subcommittee on Lake Mead, Interdivisional Committee on Density Currents, National Research Council. 2 v., 453 pp., illus. Denver, Oct. 1, 1941.

(25) United States Department of Agriculture.
Rio Puerco Watershed, New Mexico, Flood Control Survey Report. 1941. /Unpublished/

(26) United States Department of Agriculture.
Hot Springs-Wide Hollow-Eden Springs Tributary Upper Gila River Watershed, Arizona. Flood Control Survey Report 1941 /Unpublished/

(27) United States Geological Survey.
Suspended matter in the Colorado River, 1925-1941. 5 pp. /Processed/

(28) United States Geological Survey.
Surface Water Supply of the United States Water Supply Papers. (Number in parenthesis after reference number identifies paper.)

(28a) United States War Department, Corps of Engineers.
Suspended Load Records /Unpublished/

(29) Van Winkle, Walton.
Quality of the surface waters of Oregon. U.S. Geol. Survey Water-Supply Paper 363, 137 pp., illus. 1914.

Table 1.--Sediment records in Southwestern United States

Record number	Drainage basin and stream	Point of Measurement	Drainage area	Period of record	Length of record	Average annual runoff during period	Average annual runoff per sq. mile of drainage area during period	Average annual sedimentation	Average annual sediment load	Estimated specific weight	Sediment concentration in runoff	Average annual sediment production per sq. mile of drainage area	Estimated long-term average annual sediment production per sq. mile of drainage area
			Sq.miles		Years	Acre-feet	Acre-feet	Acre-feet	Tons	Lbs./cu.ft.	Percent	Tons	Tons
	GREAT BASIN												
	Northern Great Basin												
1	Chewaucan River	Paisley, Ore.	272	1911-1912	1	99,900 P	367	--------	12,200	----------	0.009	45	L.
	Sierra Nevada												
2a	Truckee River	Derby Div. Dam, Nev.	1,231 M	1906-1907	1-	1,152,000 P	658 G	---------	81,000	----------	0.005	66	L.
b	Truckee River	Derby Div. Dam, Nev.	1,231 M	1906-1907	1-	1,152,000 P	658 O	---------	87,000	----------	0.006	71	L.
3	Carson River	Hasen, Nev.	1,700 A	1906-1907	1	591,000 P	348	---------	97,000	----------	0.012	57	L.
4a	Owens River	Round Valley, Calif.	450 A	1906-1907	1-	244,000 P	542	---------	8,100	----------	0.002	18	L.
b	Owens River	Round Valley, Calif.	450 A	1906-1907	1-	244,000 P	542	---------	13,400	----------	0.004	30	L.
5	Walker River	Weber Res. Shurs. Nev.	2,438 AM	1935-1939	4A	180,000 A	64 O	55 M	59,895	50	0.024	25	A.
	Humboldt												
6	Bishop Creek	Metropolis Res. Elko, Nev.	22 M	1912-1939	27 A	----------	---	2.22 E	3,385	70	-----	154	175
7	Willow Creek	Willow Cr. Res. Elko, Nev.	126	1924-1939	15 A	----------	---	16.7 E	25,461	70	-----	202	250
8	Humboldt River	Rye Patch Res. Lovelock, Nev.	13,700	1935-1939	4.5	71,000 A	5	44.4 E	48,352	50	0.050	3.5	L.
	Central Great Basin												
9	Little Rock Creek	Little Rock Res. Palmdale, Calif.	68	1924-1943	19 R	----------	---	43	79,217	85	-----	1,165	1,000
10	Price Canyon	Fairmont Res. Lancaster, Calif. (No records)	2.37	1913-1939	26 A	----------	---	3.62 E	3,942	50	-----	1,663	1,000
	Eastern Nevada												
	Great Salt Lake												
11	Sevier River	Sevier Bridge Res. Juab Co., Utah	1,089 M	1908-1932	24 A	220,000 A	43 O	625	1,157,062	85	0.387	1,062	750
12	Sevier River	Rocky Ford Res. Sigurd, Utah	900 E	1890-1940	50 A	82,400 A	25 O	26.5 E	49,059	85	0.044	55	V.L.
13	Sevier River	Piute Res. Marysvale, Utah	1,878 M	1910-1938	28 A	186,400 A	76 O	257	475,784	85	0.188	253	300
14	Beaver River	Rocky Ford Res. Beaver, Utah	510	1914-1940	26 A	30,600 A	60	67 E	109,444	75	0.263	215	300
15	Indian Creek	Indian Cr. #1 Res. Beaver, Utah	12 A	1898-1940	43 A	----------	---	0.45 E	686	70	-----	57	90
16	Pine Creek	Enterprise Res. Enterprise, Utah	25 A	1909-1940	31 A	----------	---	15 E	24,502	75	-----	980	1,000
17	Pole Creek	Yankee Meadows Res. Parowan, Utah	7 A	1926-1940	14	----------	---	5.18 E	7,897	70	-----	1,128	1,200
	COLORADO RIVER												
	Green												
18	Green River	Green River, Wyo.	7,670	1905	1-	801,000 P	104	--------	132,000	----------	0.012	17	V.L.
19a	Green River	Green River, Utah	40,600	1914-1915	1+	3,746,000 P	92	---------	8,412,900	----------	0.165	207	1,641
b	Green River	Green River, Utah	40,600	1929-1941	12 W	3,543,000	87	---------	24,043,000	----------	0.499	592	1,641
	Upper Colorado												
20	Colorado River	Kremmling, Colo.	2,360	1905	1-	941,600 P	399	---------	256,000	----------	0.020	108	L.
21	Colorado River	Palisade, Colo.	8,790	1905-1906	1+	3,938,000 P	448	---------	3,130,000	----------	0.058	356	L.
22a	Colorado River	Cisco, Utah	24,100	1914-1915	1-	4,581,000 P	190	---------	9,111,000	----------	0.146	378	1,296
b	Colorado River	Cisco, Utah	24,100	1929-1941	12 W	4,939,000	205	---------	18,056,000	----------	0.269	749	1,296
23	Gunnison River	Whitewater, Colo.	7,868	1905	1-	2,315,000 P	294	---------	2,010,000	----------	0.064	255	L.
24a	Colorado River	Lees Ferry, Ariz.	107,900	1929-1933	5W	12,742,000	118	---------	186,000,000	----------	1.074	1,724	2,058
b	Plateau Area		19,300	1930-1933	4W	538,250	28	---------	62,297,500	----------	8.52	3,228	3,328
	San Juan												
25a	San Juan River	Bluff, Utah	23,900	1914-1915	1-	2,637,500 P	110	---------	16,639,000	----------	0.46	696	2,510
b	San Juan River	Bluff, Utah	23,900	1929-1941	12W	1,879,000	79	---------	44,473,000	----------	1.74	1,861	2,510
26	Animas River	Durango, Colo.	692	1905	1-	915,500 P	1,323	---------	210,000	----------	0.017	303	L.
27	Mexican Springs Wash	Mexican Springs, N. M.	32.67	1939-1940	2C	287	9	---------	37,350	----------	9.58	1,143	1,600
28	Chusca Wash	Mexican Springs, N. M.	8.67	1940-1941	2C	358	41	---------	45,800+	----------	9.41	5,283	2,950
29	Yessie Wash	Mexican Springs, N. M.	2.07	1941	1C	270	130	---------	27,700+	----------	7.55	13,382	5,000
	Lower Colorado												
30	Little Colorado River	Woodruff, Ariz.	8,100	1905-1906	1-	92,000 P	11	---------	915,000	----------	0.732	113	V.L.
31	Zuni River	Zuni Res., Black Rock, N. M.	650 A	1906-1929	24 A	24,780	38	506.6	937,869	85	2.78	1,443	2,000
32a	Colorado River	Grand Canyon, Ariz.	137,800	1925-1941	16 W	12,628,000	92	---------	200,244,000	----------	1.17	1,453	1,922
32b	Little Colorado Area		29,900	1929-1933	4 W	402,500	13	---------	41,275,000	----------	7.55	1,380	1,432
32c	Combined Middle Area		49,200	1929-1941	12 W	917,740	19	---------	74,169,000	----------	5.95	1,507	2,176
33	Virgin River	Virgin, Utah	934	1936-1941	2 C	184,145	197	---------	3,185,150	----------	1.27	3,410	3,500
33-1	Williams River	Below Planet, Ariz.	5,404	1938-1941	2.8	244,200	48	3,212 E	5,946,376	85	1.79	1,157	1,000
	Gila												
34	San Francisco River	Alma, N. M.	1,660 A	1905-1906	1+	142,833 P	86	---------	396,000	----------	0.204	239	740
35	Butler Wash	Tank No. 16, Eden, Ariz.	0.69	1936-1941	5.16	-------	---	1.22	2,259	85	-----	3,274	2,620
36	Local Wash	Tank No. 1, Eden, Ariz.	0.25	1936-1941	5 A	-------	---	0.164	296	83	-----	1,184	950
37	S. Fk. Eden Spring Wash	Tank No. 2, Eden, Ariz.	0.90	1936-1941	5 A	-------	---	0.174	330	87	-----	367	300
38	N. Fk. Eden Spring Wash	Tank No. 3, Eden, Ariz.	0.64	1936-1941	5 A	-------	---	0.226	409	83	-----	639	500
39	Goat Camp Creek	Silt Barrier, Duncan, Ariz.	11.89	1937-1939	2.25	-------	---	14.8	30,623	95	-----	2,576	2,576
40a	Gila River	San Carlos, Ariz.	12,880	1905	1-	255,600 P	20	---------	1,709,600	----------	0.49	133	900
40b	Gila River	San Carlos Res., Ariz.	12,880	1928-1935	6.33	276,600 A	21	5,829	8,886,893	70	2.364	690	900
41a	Salt River	Roosevelt, Ariz.	5,760	1905-1906	1 +	2,500,000 P	434	---------	11,700,000	----------	0.344	2,031	1,200
41b	Salt River	Roosevelt Res., Ariz.	5,760	1909-1939	30 A	838,000 A	145	4,126	6,739,821	75	0.59	1,170	1,200
42a	Verde River	McDowell, Ariz.	6,680	1905-1906	1 -	825,000 P	124	---------	1,030,000	----------	0.092	154	1,000
42b	Verde River	Bartlett Res., Phoenix, Ariz.	6,160	1939-1941	2	358,600	58	2,036 E	3,104,086	70	0.637	504	1,000
43	Agua Fria River	Lake Pleasant, Phoenix, Ariz.	1,460	1928-1941	12.9	50,660	35	624 E	1,019,304	75	1.48	698	1,800
	RIO GRANDE												
	Upper Rio Grande												
44	Rio Santa Cruz	Santa Cruz Reo., Espanola, N. M.	92	1929-1941	12 A	25,160 A	273	53.4 E	93,044	80	0.272	1,011	1,200
45	El Rito Creek	near mouth	121	1937-1941	5 (-)	17,250 E	143	---------	59,171 A	----------	0.252	489	L.
46	Rio Ojo Caliente	near mouth	515	1937-1938	2 (-)	94,525 E	184	---------	261,142 A	----------	0.203	507	L.
47	Rio Chama	Chamita, N. M.	3,202	1937-1942	6 (-)	580,993	181	---------	4,911,186 +	----------	0.622	1,534 +	2,000
47-1	Rio Grande	Chamita, N. M.	7,604	1937-1942	6 (+)	869,371 E	114	---------	813,456	----------	0.069	107	L.
47-2	Rio Grande	Espanola, N. M.	11,044 A	1937-1942	6	1,474,109 E	133	---------	7,073,817	----------	0.353	641	850
	Middle Rio Grande												
48	Rio Galisteo	U. S. Highway 85, N. M.	697	1937-1940	3 (+)	11,600 E	17	---------	595,688	----------	3.779	855	1,800
49	Jemez Creek	San Ysidro, N. M.	854	1936-1941	5 (-)W	89,783 E	105	---------	619,627	----------	0.508	726	3,500
50	Jemez Creek	Zia Pueblo, N. M.	979 A	1936-1941	5 (-)W	98,331 M	100	---------	930,689	----------	0.696	951	3,300
51	Arroyo Salado	San Ysidro, N. M.	125 A	1937-1940	4 (+)	4,050 E	32	---------	91,792	----------	1.668	734	L.
52	Rio Colorado	U. S. Highway 66, N. M.	--------	1937-1941	5 (-)	4,763 E	---	---------	328,783	----------	5.079	---	------
52-1	San Jose River	Laguna, N. M.	--------	1937-1940	4 (-)	5,870 E	---	---------	136,588	----------	1.712	---	------
53	San Jose River	U. S. Highway 66, N. M.	2,765 A	1937-1941	5 (-)	16,488 M	6	---------	1,176,243	----------	5.25	425	750
54	Rio Puerco	U. S. Highway 66, N. M.	--------	1937-1941	5 (-)	67,786 E	---	---------	10,858,740	----------	11.79	---	------
55	Rio Puerco	Rio Puerco, N. M.	5,160 A	1937-1941	5 (+)	72,634	14	---------	12,075,956 E	----------	12.23	2,340	2,800
56	Rio Puerco	U. S. Highway 85, N. M.	6,092 A	1937-1941	5 (-)	71,320 E	12	---------	13,271,295	----------	13.69	2,178	2,800
57	Rio Salado	U. S. Highway 85, N. M.	1,434	1937-1941	5 (-)	10,631 + W	7	---------	1,046,881 +	----------	7.25	730 +	3,500
58	Paguate Creek	Paguate Cr. Res. Laguna, N. M.	133	1938-1940	2 A	----------	---	12.5	19,057	70	-----	143	L.
59	Rio Grande	Cochiti Div. Dam, N. M.	11,661	1936-1943	7(-)W	1,377,140	118	---------	4,417,025	----------	0.236	379	860
60	Rio Grande	Angostura Div. Dam, N. M.	13,200 A	1936-1943	7(-)W	1,368,213	104	---------	6,600,000 E	----------	0.355	500	860
61	Rio Grande	U. S. Highway 60, Bernardo, N. M.	16,290	1937-1941	6(+)C	1,071,850	66	---------	7,149,849	----------	0.511	457	930
62	Rio Grande	San Acacia Div. Dam, N. M.	23,830	1936-1943	7(-)W	1,284,523	54	---------	21,897,000	----------	1.254	919	1,300
63	Rio Grande	San Marcial, N. M.	24,760	1897-1941	45 G	1,132,985	46	---------	20,719,586	----------	1.346	837	1,050
64	Rio Grande	Elephant Butte, Res., N. M.	26,312	1915-1935	20.25	1,091,000	41	19,138	25,009,538	60	1.687	950	1,050
	Lower Rio Grande												
65	Rio Grande	El Paso, Tex.	6,507 M	1924-1932	9 O	602,400	---	---------	885,712	----------	0.108	136	L.
66	Rio Grande	Fort Quitman, Tex.	8,138 E	1928-1932	5 C	217,600	---	---------	100,588	----------	0.034	12	V.L.
67	Rio Grande	Upper Presidio, Tex.	11,176 M	1925-1926	2 C	488,500	---	---------	2,650,000	----------	0.399	237	L.
68	Rio Grande	Lower Presidio, Tex.	33,797 M	1925-1926	2 O	2,655,000	---	---------	12,050,000	----------	0.334	357	L.
	PECOS RIVER												
	New Mexico Section												
69	Gallinas River	Sterris Res. Las Vegas, N. M.	150 A	1918-1940	22 A	----------	---	47 E	61,420	60	-----	409	550
70	Gallinas River	Las Vegas, N. M.	87	1905-1906	1 +	38,235 P	439	---------	1,900	----------	0.004	22	V.L.
71	Rio Bonito	Bonito Res., Capitan, N. M.	40 A	1931-1940	9 A	----------	---	3.28 M	4,286	60	-----	107	175
72	Rio Hondo	Roswell, N. M.	1,040	1905	1 -	78,000 P	75	--------	1,040,000	----------	0.981	1,000	A
73	Pecos River	Santa Rosa, N. M.	2,650	1905-1906	1 +	158,800 P	60	---------	1,430,000	----------	0.663	540	1,000
74	Pecos River	Alamogordo, Res., Pt. Sumner, N. M.	3,749	1937-1944	6.9	278,260	74	3,624	5,801,408	73.5	1.534	1,547	1,200
75	Pecos River	Dayton, N. M.	15,300	1905-1907	2 -	387,500 A	25	---------	3,110,000	----------	0.591	203	400
76	Pecos River	Lake McMillan, Carlsbad, N. M.	16,985	1894-1940	46 A	275,000 A	16	1,679	3,108,333	85	0.832	183	400
77	Pecos River	Lake Avalon, Carlsbad, N. M.	1,083 M	1892-1940	48 A	275,000 A	---	39.6 E	73,311	85	-----	68	L.
	Texas Section												
78	Pecos River	Red Bluff Res., Red Bluff, Tex.	2,650 M	1936-1940	4 A	240,000 A	---	1,627 E	2,657,704	73	-----	1,003	M
79	Big Aguja Canyon	Aguja Res., Toyahvale, Tex.	43	1930-1940	10 A	----------	---	8.9 E	16,477	85	-----	383	L.
80	Toyah Creek	Balmorhea Res., Balmorhea, Tex.	259	1916-1940	24 A	----------	---	23.8 E	36,285	70	-----	140	L.